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Human Factors Guidelines for Command and Control Systems: Battlefield and Decision Graphics Guidelines

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Fort Leavenworth Field Unit
Systems Research Laboratory

U.S. Army Research Institute for the Behavioral and Social Sciences

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These guidelines provide information to develop user-computer graphic interfaces. The focus is on the presentation of graphical charts used to display battlefield operations and resource data in ways that enhance fast and accurate perception, understanding, and use. The guidelines also apply to the presentation of battlefield situation displays, topographic and other maps, and graphic symbology or icons used as components of the user-computer dialogue. The guidelines apply to the development of charts produced on paper, as well as static and dynamic computer displays. Guidelines for the selection of the most appropriate graphic form among bar and column graphs, line graphs, surface graphs, pie charts, flow charts, and three-dimensional graphs are provided. Details for construction, modification, and use of these various graphic forms are presented. Examples of each major variation of the graphic forms are illustrated using fictional military units and notional data relationships.

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19. ABSTRACT (Continued)

Additionally, the guidelines provide recommendations for the selection and design of information codes, interaction techniques, overall screen layout, and other features of graphics. Intended users for the guidelines are system designers, application programmers, graphic artists, human factors specialists, software engineers, and others who participate in the development of command and control, decision support, or other information systems.

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Human Factors Guidelines for Command and Control Systems: Battlefield and Decision Graphics Guidelines

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Human Factors In Training
and Operation Effectiveness

FOREWORD

Graphics provide efficient ways to aggregate, summarize, and present information. Unit commanders use maps and graphs to assimilate a wide range of information and to facilitate quick and effective decision making. Also, the commander's staff relies on graphic displays to perform visual analysis of data and to present information supporting their recommendations. The increased use of computers in tactical operations allows an efficient means of producing graphics to support these operations. Because unclear or ambiguous charts can convey incorrect meanings to their users, the Fort Leavenworth Field Unit has compiled and presents in this report a set of human factors guidelines for the design and use of graphic displays.

The guidelines were developed through the execution of research task 1.4.4., Evaluating and Enhancing Command Staff Operations, and performed under the Memorandum of Understanding between the U.S. Army Research Institute and the Command and General Staff College, "Research and evaluation program for present and future command and control requirements and operations," dated 31 May 1983. The guidelines have been provided to the Maneuver Proponency Branch, Command, Control, Communications, and Intelligence Directorate, Combined Arms Combat Developments Activity; the User Computer Interaction Subgroup of the Department of Defense Human Factors Engineering Technical Group; and the U.S. Army Human Engineering Laboratory. Wider dissemination of these guidelines will include additional combat and materiel developers who address command and control issues. Quick and accurate presentation and interpretation of tactical information will result from the use of these guidelines in requirements definition, system development, and evaluation.

EDGAR M. JOHNSON
Technical Director

HUMAN FACTORS GUIDELINES FOR COMMAND AND CONTROL SYSTEMS: BATTLEFIELD AND DECISION GRAPHICS GUIDELINES

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Human Factors Guidelines for Command and Control Systems: Battlefield and Decision Graphics Guidelines

1. Introduction.

The role of computer graphics in command and control (C^2) systems is very promising. Static and dynamic situation map displays, topographical displays, and graphs of resources, tactical targets, unit performance and weather data are types of battlefield and decision graphic displays. Graphic displays summarize large quantities of data and potentially can enhance the users' ability to process information and to manage information. Also, when used as components of the dialogue, graphics may speed up user-computer communication and may increase the accuracy of the dialogue. Improvements in information processing, in information management, and in communication should also increase the response rate of the man-machine system to the rapid information and decision making demands of the battlefield environment. However, characteristic of any system capability, the effectiveness of computer graphics in C^2 systems and its contribution to the C^2 process are influenced by how computer graphics is implemented in the user-computer interface.

The interface links the user to the computer, enables the user to control the computer and determines how the user and the computer will communicate. An effective user-computer interface supports user-task performance. The purpose of these guidelines is to provide information that can be used to develop user-computer graphics interfaces that support performance in the cognitive, perceptual, and motor domains and that eliminate physiological discomfort and psycho-emotive disturbances. The guidelines are intended for generators of design requirements, system designers, application programmers, graphic artists, human factors specialists, psychologists, and others who participate in the development of C^2 systems. Ideally, by using these guidelines in the design and evaluation of C^2 systems, the potential benefits of computer graphics in C^2 systems can be realized.

These guidelines provide information about selected components of graphics interface design. Guidance is provided about those aspects of **graphic presentation, interactive dialogue**, and **screen format and display characteristics** which affect the efficiency with which the user can: (1) process information from computer-generated graphic displays; (2) construct and modify graphic displays; and (3) communicate with the computer to execute user requests. Suggested graphic aids and techniques, designed to enhance user performance, also are provided.

1.1. Methodology.

An extensive literature search was conducted. The literature of concern to C^2 computer graphics is voluminous and comes from a variety of fields, such as graphic arts, cartography, human factors and ergonomics, computer science, statistics, ophthalmology and biomedical engineering, command and control, and psychology. Automated literature searches and physical searches of major journals were conducted to identify the guidelines documents, journal articles, conference proceedings, annotated bibliographies, standards, technical reports and texts that are listed in the comprehensive bibliography.

The original research approach was to compile into a single volume the existing graphics guidelines published in human factors guidelines documents and military standards. However, most published guideline documents and standards do not address graphics in detail (e.g., guidelines on the use of various graphic forms, color coding, and icons are not generally provided in any detail). Therefore, the graphics guidelines in published guideline documents and military standards (e.g., Parrish, R. N., Gates, J. L., Munger, S. J., Towstopiat, O. M., Grimma, P. R., and Smith, L. T., 1983; Smith and Mosier, 1986; MIL-STD-1472C, 1983) were extracted; and where information was available, these published guidelines were elaborated upon or updated using material obtained from other sources. Also, additional guidelines were written using information from other sources, that is: (1) journal articles; (2) technical reports; (3) conference and workshop proceedings; (4) texts; and (5) other standardization projects.

While the number of references cited in the body of this research product are extensive, primary references used in developing these guidelines were:

Cleveland, W. S. (1985). The elements of graphing data. Monterey, CA: Wadsworth Advanced Books and Software.

Headquarters Department of the Army (1966, April). Department of the Army Pamphlet 325-10. Standards of statistical presentation. Washington, D.C.: Author.

Foley, J. D., Wallace, V. L., and Chan, P. (1984). The human factors of computer graphics interaction techniques. IEEE Computer Graphics and Applications, 4, 13-48.

Freeman, H. (1986). Computer graphics. In K. R. Boff, L. Kaufman and J.P. Thomas (Eds.), Handbook of perception and human performance: Volume I Sensory processes and perception (pp. 3-1 - 3-42). New York: John Wiley and Sons.

Gittens, D. (1986, June). Icon-based human-computer interaction. International Journal of Man-Machine Studies, 24, 519-543.

Knapp, B. G., Moses, F. M., and Gellman, L. H. (1982). Information highlighting on complex displays. In A. Badre and B. Schneiderman (Eds.), Directions in human-computer interactions. Norwood, NJ: Abex.

McCleary, G. F. (1981). How to design an effective graphics presentation. In P. A. Moore (Ed.), How to design an effective graphics presentation: Volume Seventeen, Cambridge, MA: Laboratory for Computer Graphics and Spatial Analysis, Harvard Graduate School of Design.

MIL-STD-1472, (1983, September). Military standard: Human engineering design criteria for military systems, equipment and facilities (rev. ed.). Washington, DC: Department of Defense.

Murch, G. H. (1985). Color graphics-blessing or ballyhoo? Computer Graphics Forum, 4, 127-135.

Newman, W., and Sproull, R. (1979). Principles of interactive computer graphics (2nd ed.). New York: McGraw-Hill.

Parrish, R. N., Gates, J. L., Munger, S. J., Towstopiat, O. M., Grimma, P. R., and Smith, L. T. (1983, April). Development of design guidelines and criteria for user/operator transactions with battlefield automated systems: Phase III Final Report: Volume II (Contract No. MDA903-82-C-0245). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Pomerantz, J. R., and Kubov, M. (1986). Theoretical approaches to perceptual organization. In K. R. Boff, L. Kaufman and J. P. Thomas (Eds.), Handbook of perception and human performance: Volume II Cognitive processes and performance (pp 36-1 - 36-44). New York: John Wiley and Sons.

Rock, I. (1986). The description and analysis of object and event perception. In K. R. Boff, L. Kaufman and J. P. Thomas (Eds.), Handbook of perception and human performance. Volume II: Cognitive processes and performance (pp. 33-1 -33-71). New York: John Wiley and Sons.

Schmid, C. F., and Schmid, S. E. (1979). Handbook of graphical presentation. New York: John Wiley and Sons.

Smith, S. L., and Mosier, J. N. (1986, August). Guidelines for designing user interface software (ESD-TR-86-278). Bedford, MA: MITRE Corporation.

Tufte, E. R. (1983). The visual display of quantitative information. Cheshire, CT: Graphic Press.

1.2. Guidelines Overview.

The battlefield and decision graphic guidelines are organized into three major sections: Graphic Presentation, Interactive Dialogue, and Screen Layout and Display Characteristics. Graphic Presentation, the most extensive of the three, is designed to answer questions about the use, selection, construction and coding of graphic displays. The application context for these guidelines is primarily computer generated graphic displays. In the organization of this section, generic guidelines are presented first. These generic guidelines are applicable to a majority of the types of graphic forms and provide prescriptions for the use (i.e., when to use a graphic presentation format as opposed to text or tables), construction, and coding of graphs.

The coding guidelines have a broader application in that they also provide information that concerns the design of the interactive dialogue. Guidelines are provided for selective highlighting; brightness coding; reverse video; blinking, flashing, or pulsating; symbol coding; color coding, and texture coding. Many diverse sources were used to derive the generic guidelines; however, Murch (1985) was the primary source used for the color coding guidelines.

Guidelines on "Graphic forms" follow the coding guidelines. These guidelines provide information about the use and the construction of specific types of graphs. A wide variety of graphs are covered to encourage their use in command and control systems. Guidelines on bar and column graphs, curve and arithmetic line graphs, surface graphs, pie charts, flow charts, map displays, and three or more dimensional forms are provided. DA Pamphlet 325-10 and Schmid and Schmid (1979) were used as the primary sources for the guidelines on graphic forms. Only in limited cases are these guidelines based upon the results of actual empirical research; rather, they typically detail the conventional practices of statisticians and graphic artists. However, in most cases, man's perceptual and cognitive capabilities and limitations provide the underlying rationale for the conventional practices prescribed for the construction of graphs.

Guidelines that address Dynamic Displays conclude the section on Graphic Presentation. These guidelines were taken from MIL-STD-1472C (1983). Minimum guidance is available concerning dynamic displays, and additional research is needed in this area to develop additional guidelines.

Interactive Dialogue addresses user-computer graphic communication and is divided into two smaller sections. In the section, Interaction Tasks, guidelines concerning the basic tasks of the interactive graphics dialogue are provided (i.e., selection, positioning, orienting, pathing, quantifying, and text entry). These tasks are used as a framework to prescribe capabilities of interaction techniques and to prescribe other interface features that are needed to permit the user to construct and modify a graphics display. Foley, Wallace and Chan (1980, 1984) and Smith and Mosier (1986) were the primary sources used to develop these guidelines.

Iconic dialogue provides guidelines concerning the use and construction of icons as a medium for user-computer communication. This section also contains an overview of the advantages and disadvantages of icons and an overview of Gestalt principles, which provide the theoretical foundation for the design of icons. The primary reference used for the icon guidelines was Gittens (1986), which contains a summary of icon design guidelines based upon an extensive review of the literature. Also, McCleary (1981), Pomerantz and Kubovy (1986), and Rock (1986) were used to compile the Gestalt principles.

The Screen Layout and Display Characteristics provides guidelines concerning selected components of the screen layout and characteristics of display devices that are important from the

computer graphics perspective. For example, information is provided about the design of menus and cursors. Information is also provided about display device characteristics (e.g., writing speed and color capability), that are important considerations when selecting a display device for computer graphics applications. The primary references used for these guidelines were Foley, Wallace and Chan (1980, 1984) and Freeman (1986).

With the exception of selected guidelines that provide information about the characteristics of display devices (e.g. Screen Layout and Display Characteristics), the guidelines do not address hardware (i.e., specific types of display devices, input devices, and output devices, and information about their use). The interested reader can consult the appropriate literature (e.g., Banks, Gilmore, Harold and German, 1983; Bournique and Treu, 1985; Engel and Granda, 1975; Freeman, 1986; Galitz, 1981; Hendricks, Kilduff, Brooks, Marshale and Doyle, 1982; Newman and Sproull, 1979; Parrish et al., 1983; Rupp, 1984; Swezey and Davis, 1983; and Treu, 1976). These guidelines are formatted in numbered paragraph format. Individual paragraphs present guidelines under the topic headings. An individual guideline narrative is followed by references to (a) any appropriate Figures, (b) other relevant guideline sections to refer to for further information and (c) primary references. Cross references are made to relevant paragraphs in MIL-STD-1472 (e.g. MIL-STD-1472 5.15.3.6.1).

1.3. Graphic Standards.

Graphic standardization projects also provide useful sources of information and tools for developing graphics interfaces (e.g., ANSI, 1984 a, b; Computer Graphics, 1979; Guedj and Tucker, 1979; Geudj ten Hagen Hopgood, Tucker and Duce, 1980; and ISO, 1980). These projects propose standards for the application programmer interface, the virtual device interface (or graphics-device software interface), and for computer graphics metafiles (device independent data bases). Van Deusen (1985) provides the most recent drafts of the seven proposed graphics standards systems that are currently competing for acceptance and provides an explanation of their differences and applications. These systems are: CORE, the Graphical Kernel System (GKS), the Programmer's Hierarchical Interactive Graphics Standard (PHIGS), the Initial Graphics Exchange Specification (IGES); the Computer Graphics Metafile (CGM); the Computer Graphics Interface (CGI); and the North American Presentation-Level Protocol Syntax (NAPLPS).

Competing for acceptance as the standard for the primary graphics-application programmer interface are the CORE system, which is the proposed Association of Computer Machinery-Special Interest Group on Graphics (ACM-SIGGRAPH) standard; the GKS; and the PHIGS. Of special interest is PHIGS, which emphasizes the support of command and control applications and other applications that require a highly dynamic and highly interactive operator interface. The principle objectives of the proposed API (Application programmer interface) standards are to provide portability for the application program across a wide range of operating systems, programming languages and interactive graphics devices.

Both the Initial Graphics Exchange Specification (IGES) and the Computer Graphics Metafile (CGM) concern computer graphics data bases and are graphics storage and transmittal standards. The Computer Graphics Interface (CGI) is a proposed universal graphics-device software interface standard and North American Presentation-Level Protocol Syntax (NAPLPS) is the only currently adopted ANSI standard for graphics-device software interfaces.

1.4. User-performance Design Goals.

An effective user-computer interface supports user-task performance. User-performance goals for interface design are:

1. The interface should support user-task performance in the cognitive, perceptual and motor domains. The interface should accommodate the user's cognitive, perceptual, and motor capabilities and limitations. Workloads in the cognitive, perceptual and motor domains should be minimized. For example, in the cognitive domain, the aiding techniques incorporated in the interface and the presentation formats used should support the users ability to extract, assimilate and analyze information.

2. The interface should not cause physiological discomfort (e.g., visual fatigue, difficulty in focusing, and optical illusions).

3. The interface should not cause psycho-emotive disturbances (e.g, boredom, panic, frustration and confusion).

1.5. Design Principles.

The design principles described below were used as the conceptual foundation for the writing of the guidelines and were primarily derived from Newman and Sproull's (1979) user-oriented, rules for graphics software design. These principles capture the essence of the guidelines. When applied throughout the development of a system in conjunction with the specific guidelines detailed in this research product, the design principles will support the development of a graphics interface that satisfies the user-performance goals.

1. Simplicity. The user-computer interface should not contain features that are too complex for the user to understand. Also, the graphics in the interface should not be too complex, in terms of: (1) structural complexity (e.g., icons that have an excessive number of graphic primitives or the use of graphic design elements that are redundant, and which compete with the quantitative information that is conveyed on a graph); (2) cognitive complexity (e.g., assigning meanings to symbols that differ from their normal usage in the user population; the presentation of critical data in graphs that are poorly constructed; or the use of logarithmic scales or three or more dimensional graphic forms with users who are not familiar with these presentation formats.); and (3) perceptual complexity (e.g., the presentation of a cluttered situation map display that is difficult to read and which uses color coding inappropriately). The interface complexity should be appropriate for the characteristics of the user population.

2. Consistency. The graphics interface should behave in a generally predictable manner. For example, procedures for deletion, zooming, and panning, and procedures for performing selection, positioning, quantifying and other interactive tasks should follow simple and consistent patterns without exceptions. Consistency will help the user form a conceptual model of the system, will help the user perform his work with minimal conscious attention devoted to his tools and their operational procedures, and will not disrupt the continuity of the user's thought processes.

Similarly, consistency should be achieved in the design of the graphic displays (e.g., construction and coding). Symbols and colors should also have consistent meanings. Consistency in these areas will permit the user to focus upon changes in data, will minimize cognitive workload, and will circumvent user confusion.

Also, the designer should attempt to maintain consistency in system performance, so that the system provides an equally consistent speed of response.

3. Flexibility. The interface should accommodate individual differences among users. For example, the interface should be flexible enough to accommodate the unique characteristics of groups of users, such as differences in knowledge, skills and abilities concerning the subject domain, and experience with computers (e.g., provide memory aids, where users can request symbol definitions or other detailed information about graphics symbology; provide analytic aids for topgraphic analysis; and provide multiple interaction techniques to support novice and expert users).

Also, the interface should be responsive to the user's task information requirements, which may not be the same for all users (e.g., provide more than a single format to assist users in identifying patterns and trends or other idiosyncracies in the data or to satisfy user differences in informational requirements; provide sequencing, panning, and zooming techniques to permit users to view areas of interest or to view an area in greater detail).

4. Completeness. There should be no obvious omissions in the set of functions or features provided (e.g., a user should be able to erase a part of an image without having to reconstruct the entire image and a user should be able to place text on a situation map display). However, completeness does not imply comprehensiveness. The interface need not contain every imaginable graphics capability, but it should contain a reasonable set of capabilities that can effectively handle user tasks and that supports the flexibility requirement, as described above.

5. Robustness. Error handling is not addressed in the guidelines. However, as a general rule, the system should always respond appropriately to user errors. Trivial errors of omission or repetition should be corrected without comment from the system. Serious errors should be reported in the most helpful manner possible; and only in extreme situations, should user errors cause termination of execution. Rules of interpersonal interaction observed in human communication, such as cordiality, politeness, tactfulness and restraint, are applicable to the user-computer dialogue.

2. Graphics Presentation.

Graphics show spatial, temporal, or other relations among data by special formatting of graphic elements. This section provides information and guidance on when and how to present data in a graphics format. The guidelines are designed to answer questions about the use, selection, construction, and coding of numerous graphic forms. The application context for these guidelines is primarily computer generated graphic displays, i.e., displays automatically created by the computer to represent data in the computer data base. Guidelines that concern user construction and modification of graphics displays primarily appear in the section, Interaction Dialogue. However, selected guidelines detailed below are relevant also to user-computer graphics interaction.

2.1. Use. Consider graphics rather than text description or tables in the situations described.

2.1.1. Relations. A graphics format is appropriate to show relations in space or time.

Foley and Van Dam (1982); MIL-STD-1472 5.15.3.6.1; Stewart (1980); Smith and Mosier (1986).

2.1.2. Scan and compare. When users must quickly scan and compare related sets of data a graphics format is appropriate.

Cleveland (1985); Engel and Granda (1975); MIL-STD-1472 5.15.3.6.1; Smith and Mosier (1986).

2.1.3. Monitor. When users must monitor changing data, a graphics format can be used effectively.

Smith and Mosier (1986); Tullis (1981).

2.2. Selection. Ideally the graphic form that best supports the information requirements of the user should be employed. Use the following guidelines in place of or in addition to task information referents to select an appropriate graphic form.

2.2.1. Data, objectives and user characteristics. Consider the nature and characteristics of the data (e.g., range and scale of measurement), purpose and emphasis of the message to be conveyed, and user characteristics when selecting a graphic form.

Pfeiffer and Olson (1981); Schmid and Schmid (1979).

2.2.2. Graphical-perception tasks. Quantitative data should be encoded on a graph so that the visual decoding involves tasks as high in the ordering of elementary graphical-perception tasks, as possible. The elementary graphical-perception tasks ranked in descending order by accuracy of human performance are:

1. Position along a common scale
2. Position along identical, nonaligned scales
3. Length
4. Angle-Slope

5. Area
6. Volume
7. Color hue-color saturation-density

Cleveland (1985).

2.2.2.1. Distance and detection. Consider distance and detection when selecting a graphic form based upon the ordering of the elementary graphical perception tasks.

a. A decrease in the accuracy of perceptual jugments may be associated with an increase in the distance between the data values on the graphics display. Specifically, an increase in the distance between the graphical elements that encode the data values can increase the number of errors in judgment.

b. Detection is the ability of the user to see the graphic elements on the data display either simultaneously or by nearly effortless scanning. For example, legibility and the ability to discriminate visually between graphic elements must be considered when selecting and constructing a data display based upon the ordering of the elementary graphical perception tasks.

Cleveland (1985).

2.2.3. User selection. As possible to do so, allow the user to select the graphic format that best satisfies the informational needs.

2.2.4. Multiple formats. As necessary, provide more than a single format to assist the user in identifying patterns trends or idiosyncracies in the data and to satisfy user differences in information requirements.

See 2.5.2.6.2. Differences of curves; 2.5.2.6.3. Trend lines; 2.5.2.6.4. Residuals.
Tufte (1983).

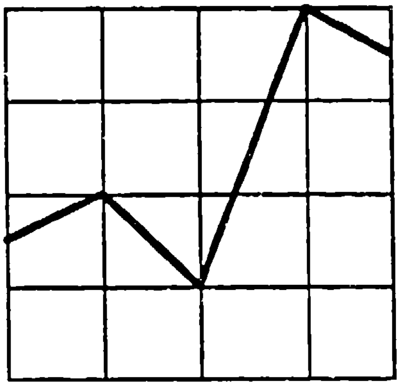
2.3. Construction. Graphic displays should be designed in a consistent format. Consistency in design is important because it permits the user to focus on changes in data without being distracted by changes in display format. This section reviews basic principles of construction that are generally applicable to most graphic forms. Use these guidelines to achieve consistency in the design of graphic displays. The section, Graphic Forms, provides additional principles of construction that are idiosyncratic to specific graphic forms.

Smith and Mosier (1986); Tufte (1983).

2.3.1. Scales.

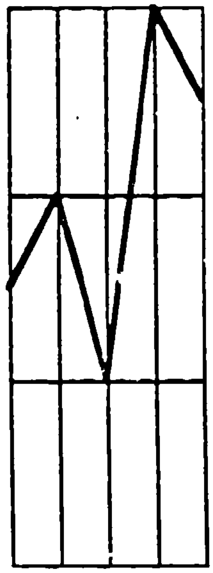
2.3.1.1. Selection. Choose scales that give a true picture of the data. Altering the scales of a graph may expand or contract the image or representation of the data and may change the way the information is perceived and interpreted.

See Figure 1.
DA PAM 325-10 (1966); Tufte (1983); White (1984).



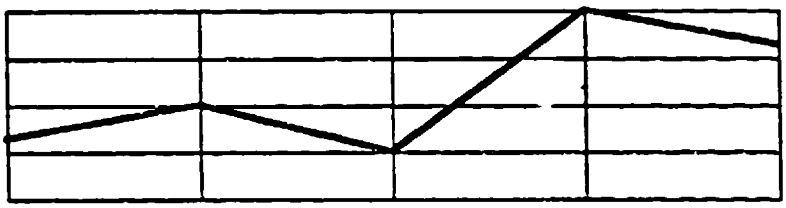
(a)

Neutral. In this arithmetic line graph neither scale is exaggerated. The vertical and horizontal scales are equal, creating a square grid. The curve shows changes that are neutral to moderate.



(b)

Dramatic. The vertical scale is exaggerated in this graph of panel "a" data. The curve shows changes that are dramatic, rapid, and sudden.



(c)

Flat. The horizontal scale is exaggerated in this graph of panel "a" data. The curve shows changes that are sluggish, slow and flat.

Figure 1. Illustration of the effects of scale alteration on the perception and interpretation of information.

Note. From Using charts and graphs: 1000 Ideas for visual persuasion (p. 169). by J. V. White, 1984. New York: R. R. Bowker Company. Copyright 1984 by Jan V. White. Adapted by permission.

2.3.1.2. Consistent scaling. When graphics data are to be compared across a series of graphs, use the same scales for each graph.

a. It may be difficult for users to compare data sets that are scaled differently. Users may overlook that the scales are different and interpret the data erroneously.

b. As an alternative to displaying separate graphs, consider combining the graphics into a single graphic format, as possible to do so.

See 2.5.2.6.1.5. Index scales; 2.5.2.2.1. Multiple slope curve graph; 2.5.2.3.1. Multiple step curve graphs; 2.5.2.6.1. Special scales.
Cleveland (1985); Smith and Mosier (1986).

2.3.1.3. Linear scales. Except where system requirements clearly dictate nonlinearity to satisfy operator information requirements, linear scales should used in preference to nonlinear scales.

See 2.3.1.4. Logarithmic scales.
MIL-STD-1472 5.2.3.1.4.

2.3.1.4. Logarithmic scales. For users who are familiar with logarithmic scales, consider using a logarithmic scale :

a. When it is important that the user understand rates of change, percent change, or multiplicative factors.

b. To improve resolution and to help the user do a better job of grasping and analyzing data.

See 2.5.2.6.1.6. Logarithmic amount scales.
Cleveland (1985); DA PAM 325-10 (1966); Schmid and Schmid (1979); Smith and Mosier (1986); Tukey (1977).

2.3.1.5. Multiple scales. Generally, the use of multiple amount scales on the same graph should be avoided and used for specialized purposes only.

See 2.5.2.6.1. Special scales.
Schmid and Schmid (1979).

2.3.1.6. Three dimensional scales. The use of three dimensional scales (i.e., the plotting of multivariate data using x, y, and z-axes) should be restricted to special applications for users who are familiar with them.

a. As an alternative to three dimensional scales consider showing a third dimension with auxiliary coding (e.g., shape or color coding) or use pictographic symbols or multiple displays to present multivariate data.

b. When three dimensional scales are used, adopt a consistent method of representation (e.g., isometric or orthographic projection, perspective drawing, or triangular coordinate grid).

See 2.5.7. Three or more dimensional forms; 2.4.6. Color coding.
Smith and Mosier (1986).

2.3.1.7. Scale axes. The axes of graphs shall have major scale divisions (tick marks) which shall be numbered or labeled. The axes of graphs shall be labeled with their description and unit of measurement.

See 2.3.1.8. Scale divisions.
MIL-STD-1472 5.15.3.6.4.

2.3.1.8. Scale divisions.

a. Major scale divisions shall be easy to read (e.g., shall progress by 1, 2, or 5 units or decimal multiples, thereof) and should cover the entire range of the data. Awkward divisions (e.g., odd intervals of 7, 11, 13, etc.) shall be avoided and used only where it is appropriate for the data plotted (e.g., the seven days of the week, or 12 months of the year).

b. Minimize the number of major and intermediate scale divisions. As possible, use less than 10 or 12 major scale divisions; and use no more than nine intermediate scale divisions.

See 2.3.2. Grid.
MIL-STD-1472 5.2.3.1.5; Schmid and Schmid (1979); Smith and Mosier (1986).

2.3.1.9. Scale numerics.

2.3.1.9.1. Zero. Display scale should start at zero, except where this would be inappropriate for the function involved. For example, do not include zero when its inclusion would severely compromise the resolution of the data.

See 2.5.1.1. Bar graphs; 2.5.2.1.2. Grid.
Cleveland (1985); MIL-STD-1472 5.2.3.1.6.2.

2.3.1.9.2. Whole numbers. Except for measurements that are normally expressed in decimals, whole numbers should be used for major graduation marks.

MIL-STD-1472 5.2.3.1.6.1.

2.3.1.10. Scale break. Avoid breaking the scale, as possible to do so. If a scale break is necessary, use a full scale break; and do not connect numerical values on the two sides of a break.

See 2.5.1.1.1.6. Breaking a bar; 2.5.2.1.2. Grid.
Cleveland (1985).

2.3.2. Grid. A grid, rectangular in shape, consists of two vertical scale lines, two horizontal scale lines, and horizontal or vertical scale rulings drawn inside the grid (grid lines). The grid bounds the data region, the area for plotting data. Grids should generally be used when presenting data in a graphics format.

2.3.2.1. Grid lines. Horizontal and vertical grid lines guide the eye in locating and reading points on a graph. Use grid lines when presenting data in a graphics format; however, grid lines should not obscure data and should be clearly distinguishable from the data.

2.3.2.1.1. Principles. Consider these general principles when constructing a grid.

a. Minimize the number of grid lines; however use enough grid lines so the user can obtain an approximate reading of the data values. Too many grid lines may clutter the display, obscure data and make the display harder instead of easier to read.

b. Grid lines may be omitted or suppressed when data values can be read using tick marks. However, grid lines and tick marks are usually necessary to obtain approximate readings of data values, except for very small graphs.

c. Most graphs will not need more than 8 or 10 vertical or horizontal grid lines.

d. Graphs that are to be read precisely need more grid lines than those meant to give a general picture.

e. Use more grid lines with wide graphs than with narrow graphs and more with tall graphs than with short graphs.

f. Grid lines should be thinner than data lines or curves, and should not be visible through bars, columns or other graphic or pictorial data elements (i.e., they should not cross them). The zero line or other base line is made broader than other grid lines.

2.3.2.2. Graphic aids. To both minimize the number of grid lines and satisfy the user's individual preference or information requirements (i.e. differences among users in the degree of accuracy or amount of detail needed from the graphics display):

a. Consider placing the suppression and presentation of grid lines under user control.

b. Consider providing a capability where the value of any data point selected by a user is displayed automatically.

c. Consider providing a capability where all the data values in the graph can be displayed in a table, when requested by the user.

See 2.3.6. Graphic design elements; 2.5.2.1.2. Grid.
DA PAM (1966); Schmid and Schmid (1979); Smith and Mosier (1986).

2.3.3. Typeface. Type should be upper and lower case with simple sans-serif type fonts and with few exceptions, should be positioned from left to right, the normal orientation for reading.

DA PAM (1966); Ives (1982); Schmid and Schmid (1979).

2.3.4. Labels. When it is necessary to label graphic data elements (e.g., bars, columns, and curves) use adjacent labels in preference to keys or legends, as possible. Because contiguous labels require less movement of the eye and less remembering, they permit the user to assimilate information more efficiently than do keys or legends.

a. Labels should be concise, easily read, reasonably close to the graphic data elements, arranged to achieve a balanced composition of the graph, and in a horizontal position. With the exception of surface graphs and pie charts, labels should not be placed directly on graphic elements.

b. To connect the graphic data element and label, use arrows, lines, or slightly tapered wedges, as necessary.

c. Generally, abbreviations should not be used as labels for graphic data elements. Abbreviations are permissible if they are standard annotations that are well known by a majority of users. Computer abbreviations are not acceptable.

See 2.5.3. Surface graphs; 2.5.4. Pie charts; 2.5.6. Map displays.
DOD HDBK 761; Schmid and Schmid (1979).

2.3.5. Key or legend. When it is necessary to use a key or legend to label graphic data elements, locate the key or legend inside the grid. Locate the key or legend outside the grid when it may obscure data elements, clutter the data region or interfere with the interpretation of the data. The style and proportion of lettering in the key or legend should be the same as that in the graph.

See 2.3.4. Labels; 2.3.3. Typeface.
Schmid and Schmid (1979).

2.3.6. Graphic design elements. Eliminate or suppress graphical design elements (symbolic or pictorial features, decorative forms, three-dimensional formats, grid lines and other design elements) that are superfluous, redundant or that compete with the data. The overall graphic design should make the data visually prominent and should communicate quantitative and qualitative information rather than graphical style.

Cleveland (1985); Tufte (1983).

2.3.7. Realistic graphics. Consider using realistic graphics to focus user attention. Due to the their greater meaningfulness, realistic graphics may also be used to enhance information processing and recall. However, the number of graphical design elements should be minimized.

See 2.3.6. Graphic design elements; 3.2.3.1.1. Pragnanz; 3.2.3.1.2. Meaningfulness of form; 3.2.3.2. Concrete concepts.
Dwyer (1970).

2.3.8. Form. Graphics should tend toward the horizontal, greater in length than height, fifty percent wider than tall. However, use the data as a guide in determining the shape of the graphic when possible to do so.

Tufte (1983).

2.3.9. Reproduction. A graph's visual clarity must be preserved when reduced or printed.

Cleveland (1985); DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.4. Coding. Coding is a means for representing and formatting display components to support the user-computer dialogue and to maximize symbol differentiation to facilitate user information extraction, assimilation and analysis of graphic displays. In addition, coding is used to portray data on a graphics display (e.g, symbol coding). Coding is also a means for highlighting display components to focus user attention and to help the user locate and monitor critical data. General guidelines concerning how and when to use coding and specific methods of display coding are provided.

a. Coding should not reduce legibility, cause visual fatigue, be irritating or increase transmission time.

b. Consistent meanings should be assigned to symbols and other codes, from one display to another.

c. The codes used for the display should conform with accepted procedures and general user expectations. For example, use standard military symbology on battlefield situation map display, and use red to code a graphic symbol which indicates an emergency condition.

d. Coding methods can be combined to enhance their effectiveness in differentiating display elements and in focusing user attention, especially for high density displays.

e. The code values used should be assigned in an orderly fashion. A logical or orderly assignment of code values will help users perceive and remember the categories coded.

See 2.4.5. Symbol coding; 2.4.6. Color coding; 2.5.6.2.2.1. Coding techniques; 3.2. Iconic Dialogue.
Knapp, Moses and Gellman (1982); MIL-STD-1472 5.15.3.3.1; Parrish et al. (1983); Smith and Mosier (1986).

2.4.1. Selective highlighting. Selective highlighting is the use of a coding method to emphasize important display components that require user attention. Highlighting makes the component(s) of interest more visually prominent than other components on the display.

2.4.1.1. Critical information. Use selective hightlighting on graphics displays to call attention to unusual values or information, to identify graphics data or symbology that have been updated or that should be updated, to identify search targets and to call attention to special areas or features of the display.

2.4.1.2. Graphic interaction tasks. Use selective highlighting to assist the user in the performance of graphic interactive tasks, i.e., tasks performed to enter graphics data, to construct, to edit and to manipulate graphics display elements.

See 3.1. Interaction tasks.

2.4.1.3. Extent of use.

a. Highlighting is most effective when used sparingly, i.e., to accentuate a few items on a display that is relatively uniform in appearance except for the hightlighted items.

b. Highlighting should be removed when it no longer has meaning. For example, highlighting, used to identify critical fire missions, should be removed when the missions have been fired.

Knapp, Moses and Gellman (1982); Smith and Mosier (1986).

2.4.2. Brightness coding. Avoid the use of brightness coding as the single coding strategy, as possible to do so. When used as the single coding strategy, consider restricting brightness coding to applications that only require differentiation between two categories of displayed items, i.e., use a two-valued code, bright and dim.

a. An effective brightness coding strategy could perhaps consist of up to three to four brightness levels. However, the brightness levels used may not be equally discernible at all levels of display intensity and under varying conditions of ambient light (fluorescent, incandescent or daylight). Differences in the brightness levels in various regions of the display may also cause visual fatigue.

2.4.2.1. Combined with other methods. Brightness coding can be used with other coding strategies to increase symbol differentiation and the overall effectiveness of the display (e.g. color).

2.4.2.2. Precautions. For systems where users can control the overall intensity of the display, test to verify that any brightness coding used is distinguishable at all levels of display intensity. Also, consider testing the effectivenss of the brightness coding under varying conditions of ambient lighting.

See 2.4.6. Color coding.
Parrish et al. (1983); Smith and Mosier (1986).

2.4.3. Reverse video. Reverse video, which is also called brightness inversion, is implemented as a change in the contrast between the display background and its components. For example, dark characters on a bright background are changed automatically to bright characters on a dark background or vice versa. Consider using reverse video to implement selective hightlighting, specifically to hightlight critical information and to support user performance of graphic interaction tasks (e.g., attribute selection and selection of graphic elements for editing or deletion).

See 2.4.1. Selective hightlighting; 3.1.1.4. Hightlighting.
Parrish et al. (1983); Smith and Mosier (1986).

2.4.4. Blinking, flashing, or pulsating. Use blink coding to focus the user's attention for *urgent* items only, (e.g., for mission critical events). Blink coding should be used rarely; but can be effective to draw initially the users attention to urgent items. Blink coding is disadvantaged because blinking may reduce legibility, may cause visual fatigue and may be irritating to the user if it persists and cannot be cancelled.

a. Use blink coding only for situations where alerting the user to the urgent information portrayed by the graphic element or other display item outweighs the disadvantages associated with its use.

b. Blink coding should be used only in applications where the blinking can be turned off by the user.

2.4.4.1. Blink rate. A blink coding strategy should employ no more than two blink rates. When a single blink rate is used, the rate shall be between 3 and 5 blinks per second. Where two rates are used, the second rate shall be less than 2 per second.

2.4.4.2. Blinking marker symbol. To focus user attention to the urgent graphic element or display item, consider adding a blinking marker symbol to the display. To preserve the legibility of the graphic element, blink the marker rather than the element. This technique is most appropriate for low-moderate density displays.

MIL-STD-1472 5.15.3.3.2; Parrish et al. (1983); Smith and Mosier (1986).

2.4.5. Symbol coding. Symbol coding may be employed to support user information processing of graphic displays (extraction, assimilation and analysis), to encode data on a graphics display and to support the user-computer dialogue. As applicable, symbols should be analogs of the event, process or element they represent or be in general use and well known to the expected users. Also, each symbol used should represent a unique element, event, or process and should be readily distinguishable from other symbols.

2.4.5.1. Standard symbols. Establish standard meanings for all graphics symbology and use the symbology consistently within the system and among systems with the same users. When available for the application, standard symbology should be used (e.g., standard military symbols and American National Standard Institute symbology for flowcharts and process charts).

See 2.5.5.3. Process charts; 2.5.6. Map displays.
American Society of Mechanical Engineers (1980); FM 101-5-1.

2.4.5.2. Size. Using size as an attribute for symbol coding generally is not recommended for high density displays and should be restricted to displays of low-moderate density. Two or three different sizes is a practical limit.

See 3.2.3.7. Size and location.
Engel and Granda (1975); Smith and Mosier (1986).

2.4.5.3. Symbol definitions. Consider incorporating capabilities in the interface that will permit users to request symbol definitions or other detailed information about the graphics symbology. For example, symbol definitions and additional information could be presented in a legend, a supplementary display, or accessed by pointing at the symbol. These capabilities can serve as memory aids and can assist users who may be unfamiliar with the graphics symbology. Also, the capabilities are especially critical to user performance when a significant amount of the graphics symbology is system-specific.

See 2.5.6. Map displays.
Smith and Mosier (1986).

2.4.6. Color coding. Color is becoming increasingly more available in computer systems. Users generally prefer color displays and find them more appealing. To a great extent, availability,

user preference, and user attitudes explain the widespead use, and in some instances indiscriminate use, of color in graphic displays. This section will detail with the latest knowledge on how color can be used effectively as a coding strategy to circumvent adverse effects on user perception. Generally, the designer should use color coding conservatively, should use color codes for special purposes, and should avoid the tendency to use color because it is a system attribute that is appealing to users.

2.4.6.1. Conservative use. Color is a very dominant coding dimension; and when it is present, viewers may fail to see relationships coded in other visual dimensions. Color also can create clutter. Performance with color codes is less accurate than most elementary graphical presentations. Therefore, color should be used conversatively.

Cleveland (1985); Hopkin (1983); Smith and Mosier (1986); Williges and Williges (1984).

2.4.6.1.1. Drawing attention. Use color to draw attention to information when the prominence of the information has to be sustained for some time. A flashing coding perhaps more effective for initially drawing attention to information but becomes irritating if flashing persists and cannot be cancelled.

a. As appropriate to the overall coding strategy, use both brightness and saturation to focus the viewer's attention to a particular area of a display. The brightest and most highly saturated area of a color display will immediately draw the viewer's attention.

See 2.4.6.2.5. Brightness; 2.4.6.3.1. Saturated and spectrally extreme colors; 2.4.6.3.2. Warm and cool colors.
Hopkin (1983); Murch (1985).

2.4.6.1.2. Critical distinctions. Use color to make important or critical distinctions in the data (e.g., to show out-of tolerance data, newly entered data, to differentiate groups or classes of information in complex, dense or critical displays and to emphasize important data fields).

Hopkin (1983); MIL-STD-1472 5.15.3.3.7; Williges & Williges (1984).

2.4.6.1.3. Search tasks. Color can be used effectively to aid search tasks when the color of the sought item is known.

Carter and Carter (1981); Woodson, 1981.

2.4.6.1.4. Categorical data. Color can be very effective for displaying categorical or qualitative data. However, color should not be used to convey the relative magnitude of the values of a quantitative variable.

Cleveland (1985); McCleary (1981).

2.4.6.2. Cautions.

2.4.6.2.1. Allowance for color blindness or weakness. Color coding should allow for potential color blindness or color weakness. Approximately 4 percent of users are affected by color blindness, 8 percent of men and 0.4 percent of women. These persons can still use multicolor displays, but may confuse certain colors such as green and yellow.

See 2.4.6.6. Aids to color identification.
Robertson (1983).

2.4.6.2.2. Monochromatic displays and printing. A redundant coding strategy should be used when color coded data will be accessed from monochromatic as well as color terminals and when the data will be printed. Color and shape or color and patterns are acceptable redundant coding strategies.

MIL-STD-1472 5.15.3.3.7; Smith and Mosier (1986); Williges and Williges (1984).

2.4.6.2.3. Consistency. Colors should have the same meanings on different displays of the same system. Inconsistent meanings may lead to errors and user misunderstandings.

See 2.4.6.5.5. Color meaning.
Hopkin (1983).

2.4.6.2.4. Small areas. Avoid the need for color discrimination in small areas of a display. The size of a colored area effects its perceptual properties. Small areas are susceptible to color loss and small areas of color can mix. Also, the human visual system produces sharper images with achromatic colors.

a. To convey fine detail in a small area, use achromatic colors (black, white, and grey) and use chromatic colors for larger panels or for attracting attention.

b. Blues and yellows are susceptible to small area color loss. Red and green used in successively smaller areas of a display eventually will be integrated by the visual system into yellow.

Murch (1985).

2.4.6.2.5. Brightness. Lightness and brightness can be distinguished on a printed hard copy, but not on a color display. A color display does not allow lightness and brightness to be varied independently.

a. Older users may need higher brightness levels to distinguish colors on a display.

b. Use brightness as well as color to differentiate multi-colored images. Difficulty in focusing results from edges created by color alone, and our visual system depends on a brightness different at an edge to achieve clear focusing.

Murch (1985).

2.4.6.2.6. Ambient light. Colors should be discernible under varying conditions of ambient light. Colors change appearance as the light level is increased or decreased; and displays change color under different kinds of ambient light: fluorescent, incandescent, or daylight.

a. Colors also change due to increased or decreased contrast with the background color and shifts in the sensitivity of the eye.

See 2.4.6.4.1. Contrast; 2.4.6.6. Aids to color identification.
Murch (1985).

2.4.6.2.7. Detecting change in color. When gradual color changes will be used as an element of a coding scheme, consider the fact that the magnitude of a detectable change in color varies across the spectrum. For example, small changes in extreme reds and purples are more difficult to detect than small changes in other colors such as yellow and blue-green. Also, changes in green are not perceived readily by the visual system.

a. Colors are not equally discernible. To perceive a color difference, a large change in wavelength is needed in some portions of the spectrum and a small one in other portions.

Murch (1985).

2.4.6.3. Use of specific colors.

2.4.6.3.1. Saturated and spectrally extreme colors. Hues differ in saturation levels. For example, yellow always appears to be less saturated than other hues.

a. The simultaneous display of highly saturated, spectrally extreme colors should be avoided.

b. Reds, oranges, yellows, and greens can be viewed together without viewer refocusing, but cyan and blues cannot be viewed easily with red. Therefore, to prevent frequent refocusing and visual fatigue, avoid the use of extreme color pairs such as red and blue or yellow and purple.

c. Desaturating spectrally extreme colors will reduce the need for refocusing.

Durrett and Trezona (1982); Hopkin (1983); Murch (1985).

2.4.6.3.2. Warm and cool colors. Use warm colors (long wavelength colors) to convey action or the requirement for a response. Use cool colors to indicate status or background information.

a. Generally warm colors are experienced as advancing toward the viewer and hence force attention. Viewers experience cool colors as receding or drawing away.

Murch (1985).

2.4.6.3.3. Opponent colors. Opponent colors can be used effectively together. Good combinations for simple displays are red and green or yellow and blue. The opposite combinations, red and yellow or green and blue produce poorer images.

Murch (1985).

2.4.6.3.4. Red and green. Avoid the use of red and green in the periphery of large-scale displays. The retinal periphery is insensitive to red and green; and for this reason, saturated red and green should be avoided, especially for small symbols and shapes. Yellow and blue are good peripheral colors.

a. When used in successively smaller and smaller areas of a display, red and green will be integrated by the visual system into yellow.

See 2.4.6.3.3. Opponent colors; 2.4.6.3.5. Blue; 2.4.6.2.4. Small areas.
Murch (1985).

2.4.6.3.5. Blue. Avoid pure blue for critical data, text, thin lines, and small shapes. The visual system is not set up for detailed, sharp, short-wavelength stimuli. However, blue does make a good background color and is perceived clearly out into the periphery of the visual field.

a. Avoid adjacent colors different only in the amount of blue. Edges that differ only in the amount of blue will appear indistinct.

b. Blue can be used effectively in the periphery of a large-scale display.

c. Blues and yellows are susceptible to small area color loss and should not be used in small areas of a display.

See 2.4.6.4. Background; 2.4.6.2.4. Small areas; 2.4.6.3.4. Red and green; 2.4.6.3.3. Opponent colors.
Durrett and Trezona (1982); Murch (1985); Smith and Mosier (1986).

2.4.6.4. Background.

2.4.6.4.1. Contrast. Color coded information must generally have adequate contrast with the background. Contrast ratios should be within the range of approximately 6:1 to 10:1.

Hopkin (1983).

2.4.6.4.2. Coloring.

a. Contrast is lost when the background and text colors are similar. Generally, darker spectrally extreme colors make good backgrounds. Blue also makes a good background color.

See 2.4.6.3.1. Saturated and spectrally extreme colors; 2.4.6.3.5. Blue.
Murch (1985).

b. Extensive coloring is not recommended for the background, segments of it, or particular regions surrounding individual characters.

c. If background coloring is used extensively, the display can have a much greater light output than the other displays in the environment. The total light output from the various displays in use should be matched approximately for total luminous flux. A mismatch in luminous flux can induce changes in pupil size whenever the user looks from one display to the other and cause visual fatigue.

d. When multicolored background segments are used to convey information in a dynamic display, they increase the light output from the display and make the light output variable.

See 2.6. Dynamic displays.
Hopkin (1983).

2.4.6.5. Color coding schemes.

2.4.6.5.1. Single scheme. When the color coded information will be assessed from color displays exclusively, a single color coding scheme is appropriate if the density of the display is low. For higher density displays, a double coding strategy such as color and shape or color and patterns should be used.

See 2.4.6.6. Aids to color identification.
Woodson (1981).

2.4.6.5.2. Number of colors. The benefits of color can be lost if too many colors are used. Maintaining more than five to seven elements simultaneously in working memory is difficult. A coding scheme should include no more than four to seven colors.

a. As a general rule, use no more than four colors for novice users and seven colors for experienced, long term users.

Durrett and Trezona (1982).

2.4.6.5.3. Size. Increase the size of the color-coded object as the number of colors increases.

Durrett and Trezona (1982).

2.4.6.5.4. Discrimination. Chose color coding schemes so that color discriminability is maximized.

See 2.4.6.2.7. Detecting change in color.
Carter and Carter (1982).

2.4.6.5.5. Color meaning. In selecting a color code, consider color meanings or stereotypes, e.g., red for danger warning; yellow for caution or attention; green for normal or go. The color itself may convey information that is either appropriate or inappropriate to the objectives of the display.

a. When a color coding scheme is used to differentiate data or highlight text, color stereotypes can also bias the user's qualitative judgments of the displayed information (e.g., red for bad or deficient, green for good or at an acceptable criteria level, etc). Consider these biases when making color choices; and as appropriate, avoid them or use them for added emphasis.

Murch (1985); Williges and Williges (1984).

2.4.6.5.6. Task performance. Color coding is likely to aid some tasks and hinder others. Therefore, when choosing a color coding scheme, consider all tasks that must be performed using the color coded data. Ensure that the advantage of color coding across all tasks is maximized and that unwanted sources of error for a particular task are minimized.

Hopkin (1983).

2.4.6.5.7. Order. If the task does not suggest a particular ordering for the levels of a color code, then order the colors by their spectral position, (that is, red, orange, yellow, green, blue, indigo, violet, or mnemonically - ROY G. BIV).

Ives (1982); Murch (1985).

2.4.6.5.8. Evaluation. Evaluate the effectiveness of the color coding for meaning, discriminability, useability by operators who have color-deficiencies, and all tasks for which the color coded data are likely to be used.

2.4.6.6. Aids to color identification. Consider applying the following techniques to help operators with color-vision deficiencies use color displays with fewer errors in color identification. The techniques will also help color-normal operators who must view the display under demanding or difficult conditions.

2.4.6.6.1. Comparisons. Avoid the use of green, yellow, and red comparisons for important or frequent discriminations. Instead use yellow and blue, red and turquoise, or green and pink. On 4-color machines use white and blue or blue and green.

2.4.6.6.2. Cues. Encourage the use of other cues to identify colors, such as brightness and saturation.

2.4.6.6.3. Redundant coding. Use redundant coding, monochrome compatibility, and other characteristics of the displayed format to remove the need for color discrimination.

See 2.4.6.5.1. Single scheme.

2.4.6.6.4. Legend or key. Use a legend or key so that color comparisons can be made. The key will make discrimination easier between colors if all coded dimensions are not present on a particular graph.

Robertson (1983).

2.4.7. Texture coding.

Texture codes, shading and cross-hatching patterns, can increase the complexity of a graphics display and require a key or legend when labels cannot be placed directly on the graph. In addition, many cross-hatching patterns create adverse visual effects. Shadings or tonal codes also require density judgments, which are performed less accurately than most graphical-perception tasks. Use labels in preference to texture codes whenever possible to do so. When texture coding cannot be avoided, use it to differentiate categories of data only (such as, on low-moderate density map displays, column graphs and other types of graphs). Simple texture codes should be used, and the temptation to use elaborate encoded shading and cross-hatching patterns should be avoided.

See 2.5.1.1. Bar graph; 2.5.6. Map displays.
DA PAM 325-10 (1966); Schmid and Schmid (1979); Tufte (1983); Cleveland (1985).

2.4.7.1. Vibrating graphics. Avoid using cross-hatching patterns that produce the appearance of vibration and movement (i.e. moire effects).

2.4.7.1.1. Line patterns. Do not use patterns that consist of horizontal, vertical, diagonal or wavy lines. In addition to creating adverse visual effects, these patterns can distort the areas they code and may cause the user to misread a graph. For example, a vertical line pattern used on a simple bar graph may be perceived as smaller subdivisions, and the user may interpret the simple bar graph as a subdivided bar graph.

2.4.7.1.2. Uneven spaced patterns. Patterns whose elements are unevenly spaced or that are inconsistent in their arrangment may also create adverse visual effects. Select evenly spaced patterns.

2.4.7.1.3. Coarseness: Avoid the use of very coarse patterns, which are seldom justified even when reproduction quality is a very important factor (e.g., peppermint-stick or checkerboard patterns). Coarse patterns reproduce very well; however they usually create adverse visual effects, compete with the data, and distort the areas they code.

See Figure 2.
DA PAM 325-10 (1966); Tufte (1983)

2.4.7.2. Shading and tonal coding. The tones of shading patterns should be logically arranged. When the nature of the data does not dictate the arrangement of the tones, arrange them from dark to light and do not alternate the tonal codes (i.e., dark, light, dark, etc.). Alternating shading patterns break up the unity of a display and creates adverse visual effects.

a. On graphs the strongest or darkest tone should be placed next to the baseline and weakest the farthest away.

b. On maps, order the tonal codes so that the darkest and lightest tones correspond to extreme values (e.g., dark patterns show high elevation and light patterns show low elevation).

DA PAM 325-10 (1966); Smith and Mosier (1986).

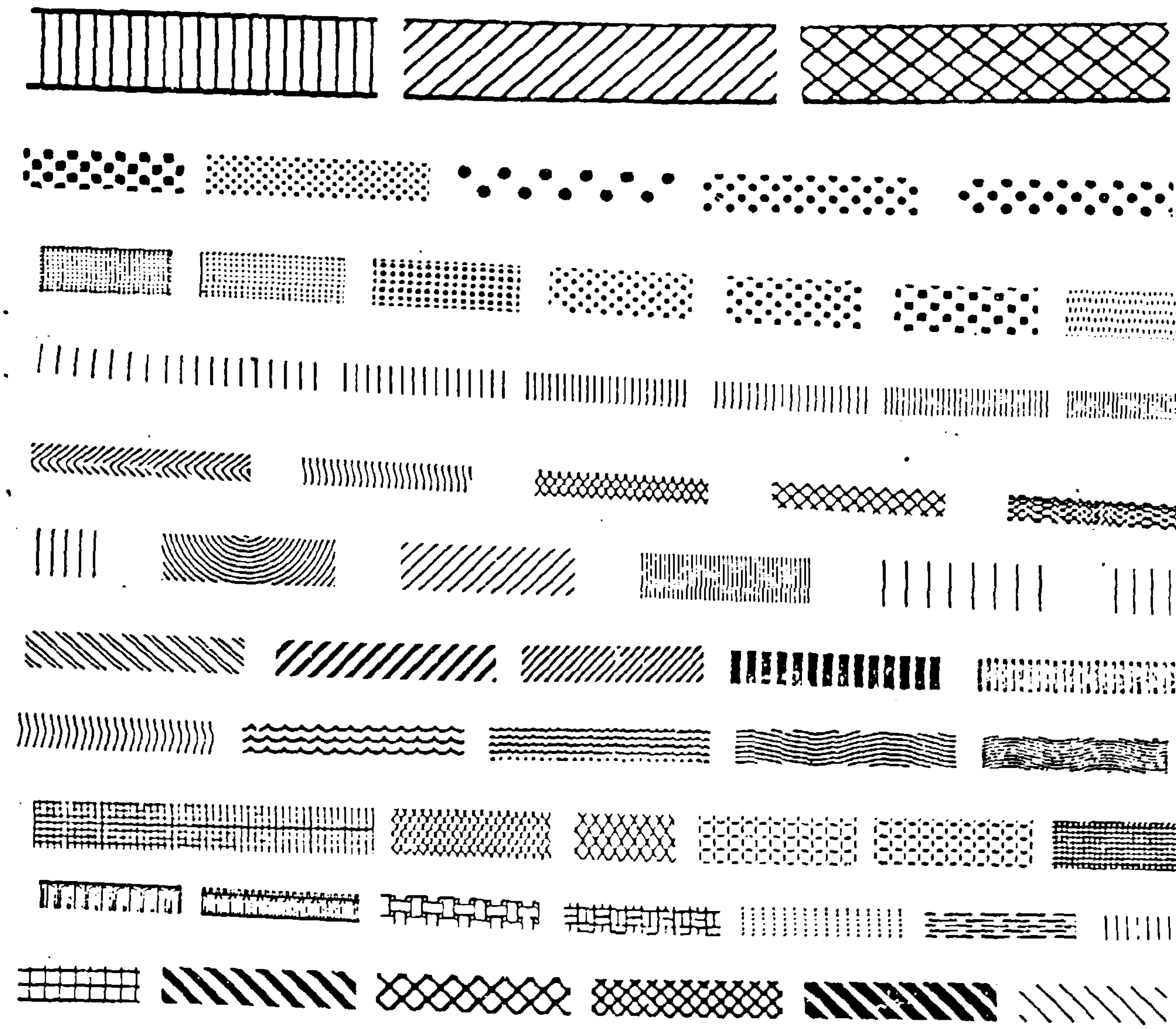


Figure 2. Vibrating graphics: Examples of cross-hatching patterns that may produce the appearance of vibration and movement.

Note. From The visual display of quantitative information (p. 111) by E. R. Tufte, 1983. Cheshire, CN: Graphic Press. Copyright 1983 by Edward R. Tufte. Adapted by permission.

2.5. Graphic Forms.

2.5.1. Bar and column graphs.

The bar graph and column graph are the two most common one-dimensional graphic forms. They show a comparative measure for different items, for parts of a total, or for a variable sampled at discrete intervals. Bar and column graphs differ primarily in the orientation of the bars. The bars are arranged horizontally in bar graphs and vertically in column graphs. Comparisons are based upon length judgments.

DA PAM 325-10 (1966); Schmid and Schmid (1979); Smith and Mosier (1986).

2.5.1.1. Bar graph.

This graph and its variations are generally used to show a comparative measure of different items. Bar graphs can be used to show how several items differ from each other in one or two characteristics, or to show how several items differ from each other in the distribution of their components.

a. Bar graphs differ from column graphs in that they typically have only one scale (an amount scale) and are not generally used to plot time series data. However, a bar graph may be used to portray temporal data when its use would be more appropriate for the specific situation.

See 2.2. Selection; 2.5.1.1.6. Grouped-bar graph.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.1. Construction.

Bar graphs typically have one scale, an amount scale that measures across the graph. The items measured are listed on the vertical dimension.

a. A bar graph has both an amount scale and a time scale when it is used to portray temporal data.

b. All bar graphs, except the range-bar graph, have a zero line or other base line.

DA PAM 325-10 (1966).

2.5.1.1.1.1. Location of scales. The amount scale should be placed at the top of the graph directly below the title. To facilitate reading, repeat the amount scale at the bottom of the graph when the graph is extremely tall and there are more than 3 or 4 scale divisions.

DA PAM 325-10 (1966).

2.5.1.1.1.2. Scale numerals. Center the numerals above the scale divisions. Shorten the numerals, as necessary, to prevent them from running together.

See 2.3.1.7. Scale Axes.
DA PAM 325-10 (1966).

2.5.1.1.1.3. Scale labels. Use a scale label for all bar graphs (e.g., percent completed, thousand, etc.). Center the label above the scale numerals. Do not provide a label for a scale that is repeated at the bottom of a graph.

See 2.3.1.7. Scale axes.
DA PAM 325-10 (1966).

2.5.1.1.1.4. Spacing and width. Use the number of bars and the size and proportions of the graph to determine the width of the bars and the spacing between them. However, the space between adjacent bars should be close enough so that a direct visual comparison can be made without eye movement.

a. The bars should be the same width and evenly spaced.

b. As a general rule, the spacing between the bars should be less than the bar width, preferably, one half the width of the bars.

c. The bars should be neither disproportionately long and narrow nor short and wide. As a general stragtegy, the shorter or closer the bars, the thinner they should be; the longer or farther apart the bars, the thicker they should be.

DA PAM 325-10 (1966); Schmid and Schmid (1979); Smith and Mosier (1986)

2.5.1.1.1.5. Ordering of bars. Order the bars so they are appropriate to the users informational requirements. For example, an alphabetical, geographical or another systematic ordering of the bars may be appropriate for the users needs. The bars are usually arranged in order of size, starting with the largest.

DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.1.6. Breaking a bar (or column). A bar may be broken when it represents an extreme data value that far exceeds the range of the amount scale ("freak bar"). When the end of a bar must be broken:

a. Break the bar beyond the last grid line.
b. Use a bold, simple break.
c. Do not show the square end of the bar.
d. Show the value of the bar in small numerals, just above or below the break.

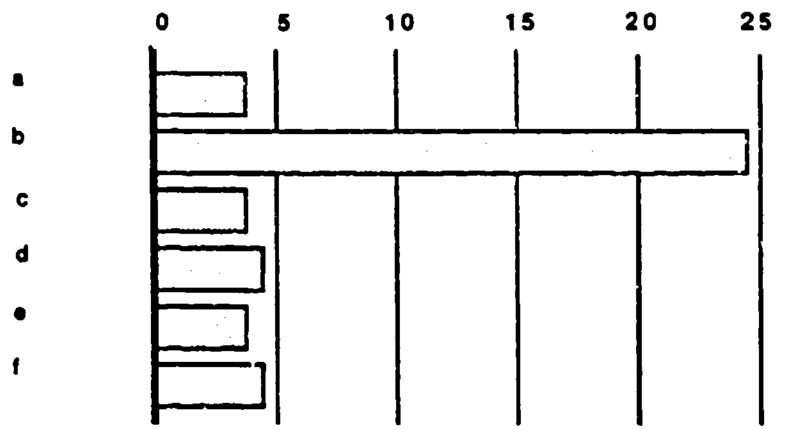
See Figure 3.
DA PAM 325-10 (1966).

2.5.1.1.1.7. Labeling a bar. Use contiguous labels in preference to keys or legends to label the bars of a bar graph, as possible to do so. Place basic data indicated by numerals at the left of the zero line outside the grid of the bar graph. Avoid placing numerals and other alphanumerics inside the bars and at the right end of bars. (e.g., number of observations or persons, value of each bar, or value of a "freak bar").

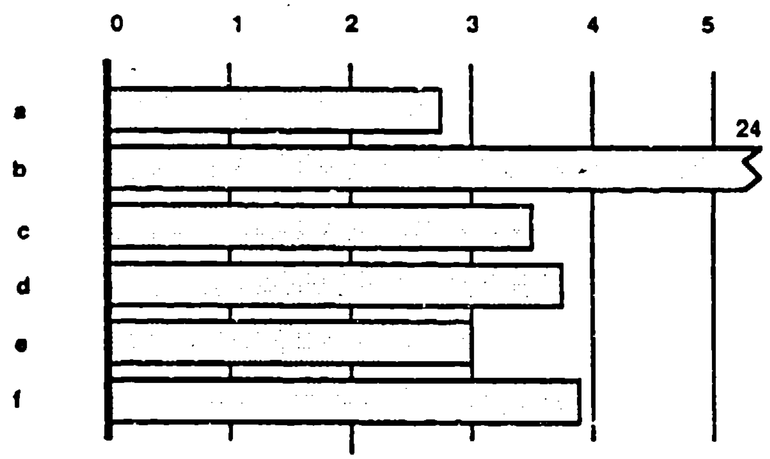
a. When making judgments of comparative lengths, the eye tends to add numerals placed at the end of the bars to its length. When the placement of numerals at the right end of bars cannot be avoided, the numerals should be relatively small in size and separated from the bar.

b. When numerals are placed inside the bars, there is a tendency to compare only the parts of the bars in which there are no numbers. Leave a strip of shading on all sides of the numerals when the placement of numerals and other alphanumerics inside the bars cannot be avoided.

See 2.3.4. Labels; 2.3.5. Key or legend; 2.5.1.1.1.6. Breaking a bar (or column).
Schmid and Schmid (1979).



a. An unusually long "freak" bar compresses the rest of the graph.



b. The scale of the graph from a. has been expanded and the long one is broken. The bar should be broken beyond the last ruling and broken with a simple, bold break. The value of the broken bar should be placed above or below the bar, not inside or beyond.

Figure 3. Breaking a bar or column.

2.5.1.1.1.8. Shading. Use shading or cross-hatching patterns in bar graphs (or column graphs) to differentiate the various categories of data plotted. Select patterns that do not produce adverse visual effects.

a. Use color to add emphasis or for specialized purposes (e.g., to draw the users attention to a total, a broken bar or other important data element).

b. Black and white should be used with caution. They are not recommended for general use.

(1) Do not use white for large areas of bar graphs and column graphs, because white will not provide adequate contrast with the background of the display surface. White is sometimes effective for very small segments if the lines of the bars or columns are heavy enough to set the bars or columns off from the background and define figure and ground relationships.

(2) Use black in small areas and for certain special purposes (e.g., to show unfavorable conditions). Because black is so visually prominent (strong), it will dominate the graph when used in large areas (e.g., suppress the perception of data shaded in other ways). However, when used in small areas it can help solve shading problems and can make the graph easier to understand.

c. Do not use outline bars or columns. Outline bars or columns generally will not provide adequate contrast with the background of the display surface and figure and ground relationships will not emerge. See b. (Black and white) above.

See 2.5.1.1.9. Change-bar graph; 2.4.7. Texture coding; 2.4.6. Color coding; 3.3.3.1. Gestalt principles. DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.1.9. Blowup Insert graph. When there is a wide range in the data, the smaller items may be barely visible on a bar graph. To support comparative judgments using the smaller items, consider using a "Blowup Insert graph" where the smaller items are presented on an expanded scale.

a. Generally, insert bars should be the same thickness as the bars in the bar graph. Bars may be made slightly narrower if there is not sufficient space on the graph.

b. Do not use an additional scale label if the insert can be placed directly opposite the item it describes. If an alternative placement is necessary the scale label should be repeated in an abbreviated format.

See Figure 4.
DA Pam 325-10 (1966).

2.5.1.1.1.0. Total Insert graph. When it is necessary to show the total and the size of the total precludes its direct placement on the graph, consider using a "total insert graph". This insert is shown at a reduced scale.

See Figure 5.
DA PAM 325-10 (1966).

2.5.1.1.2. Simple bar graph. This graph is used to compare two or more coordinate items. It is a series of horizontal bars drawn to the right of a common base line.

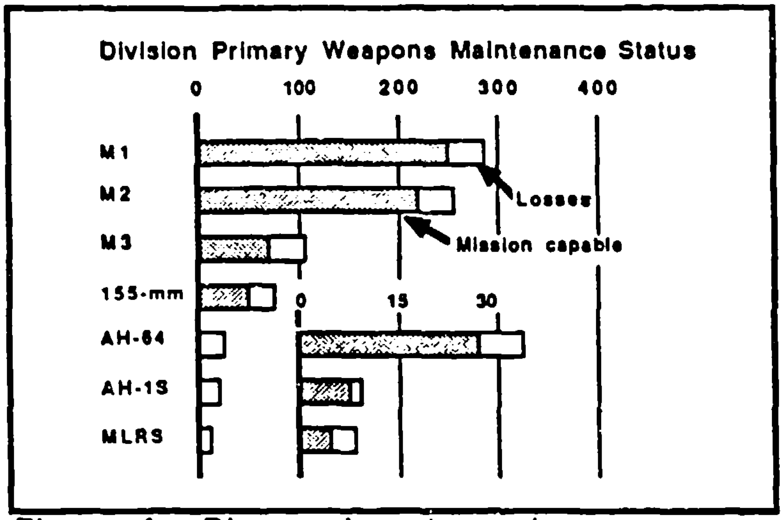


Figure 4. Blowup insert graph.

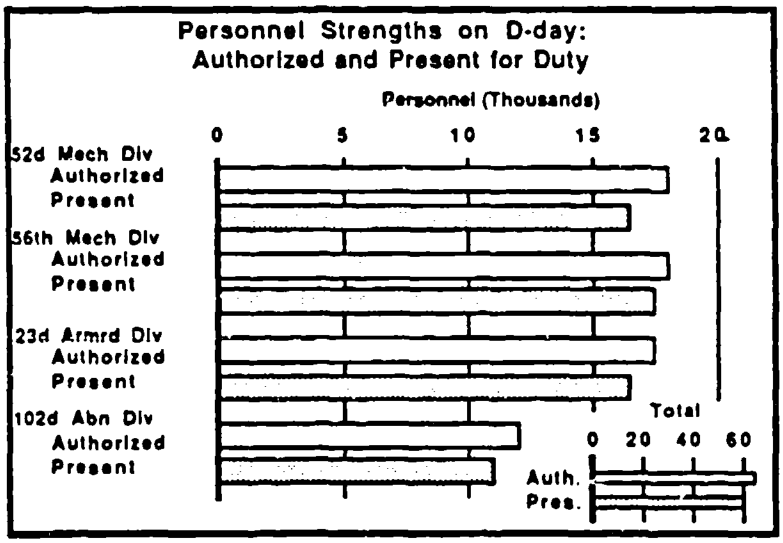


Figure 5. Total insert graph.

a. Items may be plotted according to absolute value, or may be expressed as a percentage of an appropriate total, goal, average, or other standard.

b. A single shading for all bars should be used. However, a bar used to show a different category, such as a total or average, may be set off from the other bars by a different shading or by additional space between bars.

See Figure 6.
See 2.5.1.1.1.8. Shading.
DA Pam 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.3. Subdivided-bar graph. In this type of bar graph, each bar is divided into its component parts. The subdivided-bar graph should be used to show the effect of each component on the size of the total. It is also called a segmented-bar or component bar graph.

a. The subdivided-bar graph has the disadvantage that only the component that starts from the base can be measured directly from the arithmetic scale, which is calibrated in absolute numbers.

b. By convention, the largest or most important component of each bar should be placed next to the zero line.

c. Consider using this graph in preference to multiple pie charts to show a comparative measure of totals of different sizes.

See Figure 7.
See 2.5.4.2. Pie charts: Restrictions on.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.4. Subdivided 100 percent bar graph. In this graph each bar is segmented into components that total 100 percent, regardless of the absolute size of the total value of the bar. The subdivided 100 percent bar graph should be used when it is important to show the proportional part of the total contributed by each component, i.e. the percentage distribution of the components.

a. The graph has the advantage of providing two base lines, zero and 100 percent. These base lines support direct comparisons of components at either end of the graph.

b. To prevent the inappropriate use of percentage comparisions, use this graph with caution when there is a wide difference in the absolute amounts or totals on which the graph is based.

c. Consider using this graph in preference to multiple pie charts to show the percentage distribution of a series of totals.

See Figure 8.
See 2.5.4.2. Pie charts: Restrictions on.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.5. Area-bar chart. A variation of the 100% subdivided bar chart, the area-bar chart is useful for conveying proportionate amounts of a total and the relative importance of coordinate items. In this type of bar graph, the areas (width) of bars and their subdivisions are drawn in proportion to the values of the categories and subcategories that they represent.

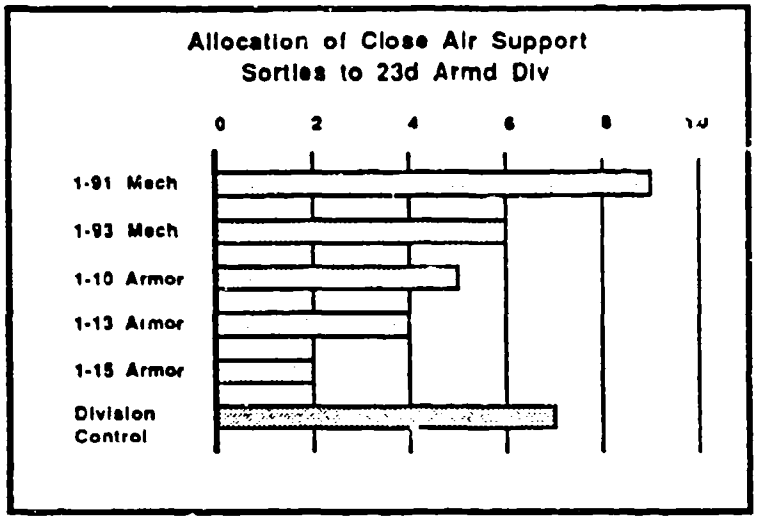


Figure 6. Simple bar graph.

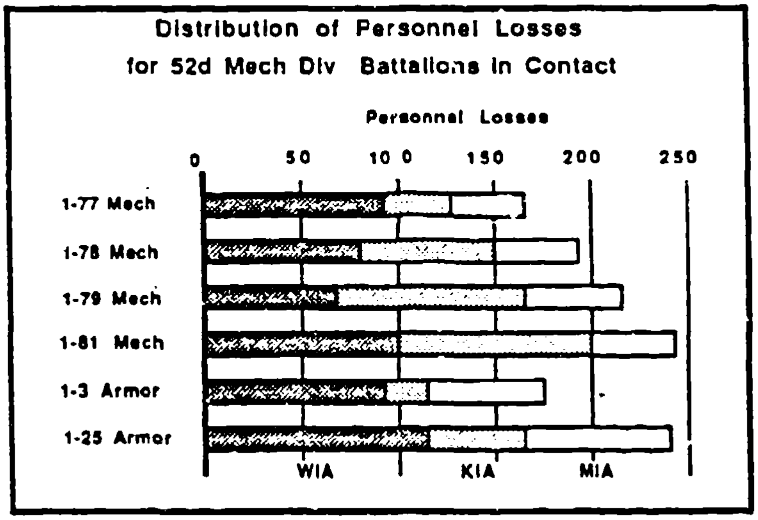


Figure 7. Subdivided bar graph.

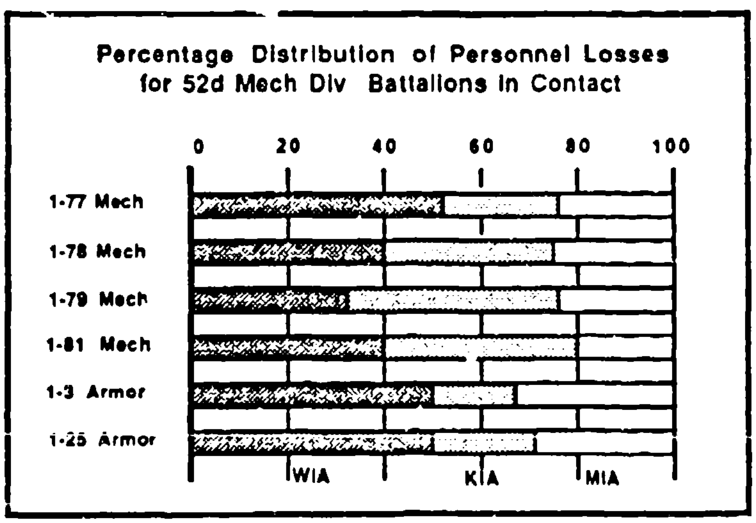


Figure 8. Subdivided 100% bar graph.

See Figure 9.
Schmid and Schmid (1966).

2.5.1.1.6. Grouped-bar graph. This type of bar graph can be used effectively when it is important to convey comparisons of magnitudes for each of two or three periods of time or for two or three categories of coordinate items. Each item in a grouped-bar graph is described by a set of bars. The paired or grouped bars are arranged in a series that spans the height of the graph.

a. The scales of a grouped-bar graph can be calibrated in absolute numbers or percentages.

b. While it is permissible to connect the bars of a item, common practice is to separate the bars for each category of an item by a small space.

c. The space between groups of bars should be no less than the thickness of a single bar.

d. When time period data are plotted, the most important category should be placed first and given a darker shading.

e. To avoid the need for overlapping, increase the height of the graph. However, when a series of paired bars takes up more space than warranted, the bars may be overlapped to reduce the height of the graph, if one set of bars stays consistently shorter than the other.

See Figure 10.
See Column graphs: Construction - Overlapping columns (or bars).
DA Pam 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.7. Bilateral-bar graphs. This category of graphs consists of three types of bar graphs: paired-bar graph, sliding bar graph and deviation-bar graph. In bilateral-bar graphs, the bars extend to the left and right of a common referent line or base line. These graphs are used for making comparisons of two contrasting variables or attributes, or for presenting positive and negative deviations, increases and decreases, or gains and losses. Bilateral-bar graphs are also called two-way bar graphs.

2.5.1.1.7.1. Paired-bar graph. This graph shows comparisons of coordinate items or groups on two distinct variables or attributes. The bars for each attribute are placed opposite each other, one to the left and one to the right of the base line. The paired-bar graph is appropriate when different units or scales must be used for each variable or attribute. As appropriate, use the convention that bars that extend to the left denote unfavorable results or considerations.

See Figure 11.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.7.2. Sliding bar graph. In this graph the length of each bar represents the total of two main components or attributes. One component of each bar extends to the left and the other component to the right of a common referent line or base line. Sliding bar graphs may be used when it is important to compare the magnitude of the components from a common base line.

a. The scale of a sliding bar graph can be calibrated in either percentages or absolute numbers.

b. The two main components of the sliding bar graph may be further subdivided. To avoid an overly complicated presentation, do not subdivide the components of a sliding-bar graph into more than three to four segments.

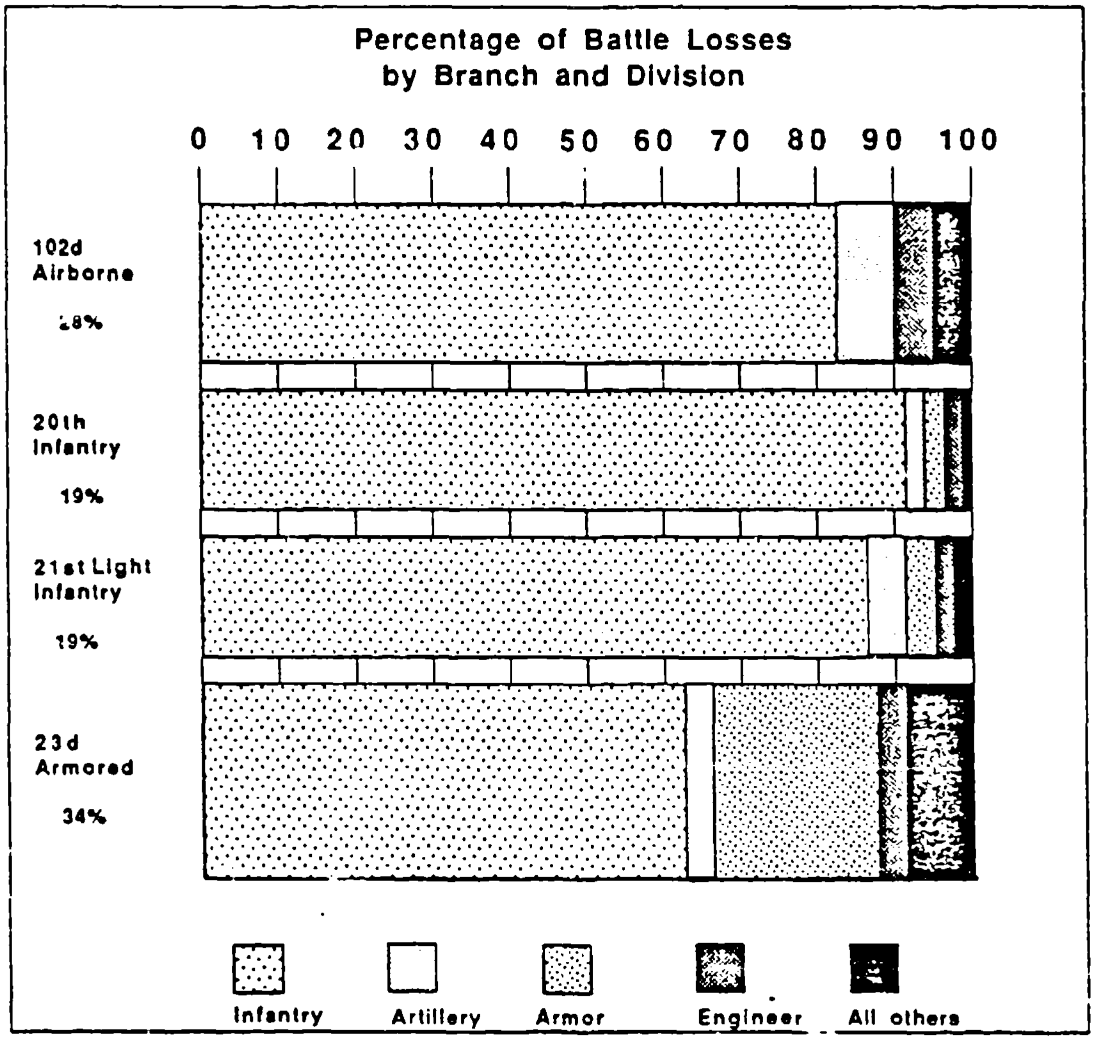


Figure 9. Area-bar chart.

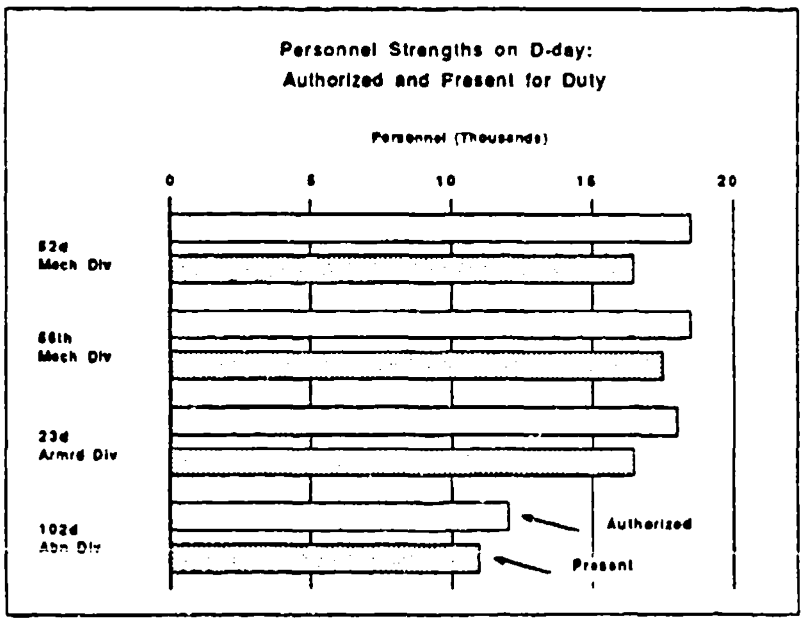


Figure 10. Grouped bar graph.

c. Shading may be used to differentiate the components and subdivisions.

See Figure 12.
See 2.5.1.1.1.8. Shading.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.7.3. Deviation-bar graph. This graph is useful for comparing differences between actual results and a standard (e.g., positive and negative deviations, increases and decreases, and net gains and net losses). Unlike the other bilateral graphs, each coordinate item on a deviation-bar graph has a single bar that extends either to the left or to the right of the reference line.

See Figure 13.
DA Pam 325-10 (1966); Schmid and Schmid (1979).

2.5.1.1.8. Range-bar graph. The use of the range-bar graph is recommended when it is important that the user know something about the distribution of the data values reported for each coordinate item. In this graph a range bar plots the minimum and maximum value amounts and permits a comparison of the difference between the high and low values plotted. Range bars are not plotted from a common base line and comparisons of ranges for different items cannot be made directly.

a. A cross-bar or some other appropriate symbol may be added to this graph to permit a comparison of data values (e.g. averages) and their underlying distributions.

b. Goals or tolerance limits may also be portrayed using an appropriate symbol such as a dashed line that extends the height of the graph.

See Figure 14.
DA PAM 325-10 (1966).

2.5.1.1.9. Change-bar graph. This graph is a variation of the range-bar graph; and it has a direction indicator (such as an arrowhead) to show change from one time to another, instead of simple range. This graph may be used effectively to show performance, the direction of the performance, and the predicted future performance of coordinate items. Also, this bar graph may be used to show performance before and after adoption of new methods or performance of an original and revised program.

a. To show data such as an objective or other bench mark, best previous performance or predicted future performance appropriate graphical symbology that does not clutter the display may be used.

b. By convention, unfavorable changes are shown with black bars; however, "red" may also be appropriate for the data.

See Figure 15.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.2. Column graphs. This graphic form and its variations are generally used to show time series data when the number of values plotted is not very large (e.g., to compare data for a single item or several items measured at discrete intervals). In column graphs, the bars are arranged vertically and there are generally two scales. The vertical scale shows amount and the horizontal scale shows time. Column graphs are also used to show component relations (e.g., the component parts of a total or a series of totals).

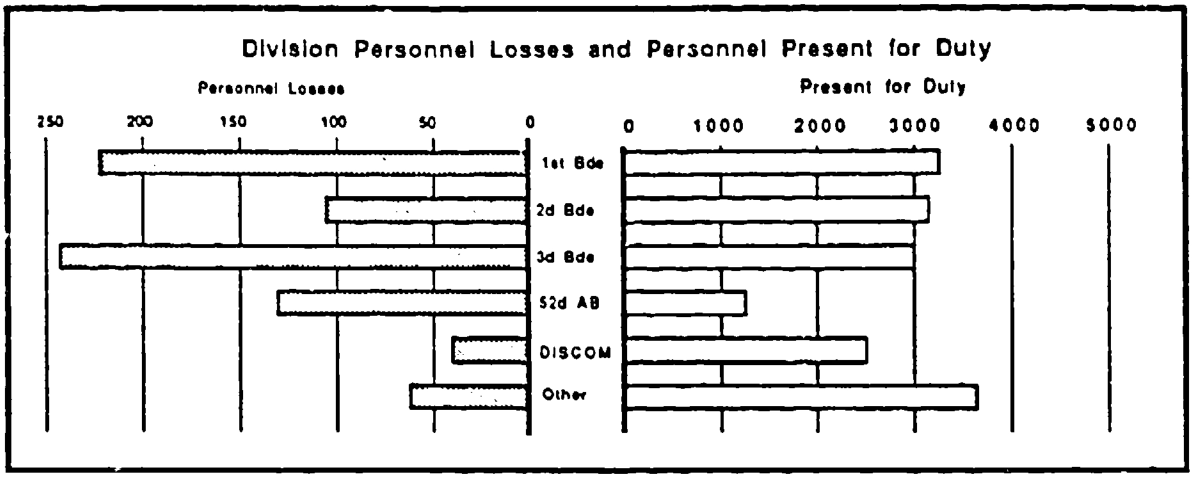


Figure 11. Paired bar graph.

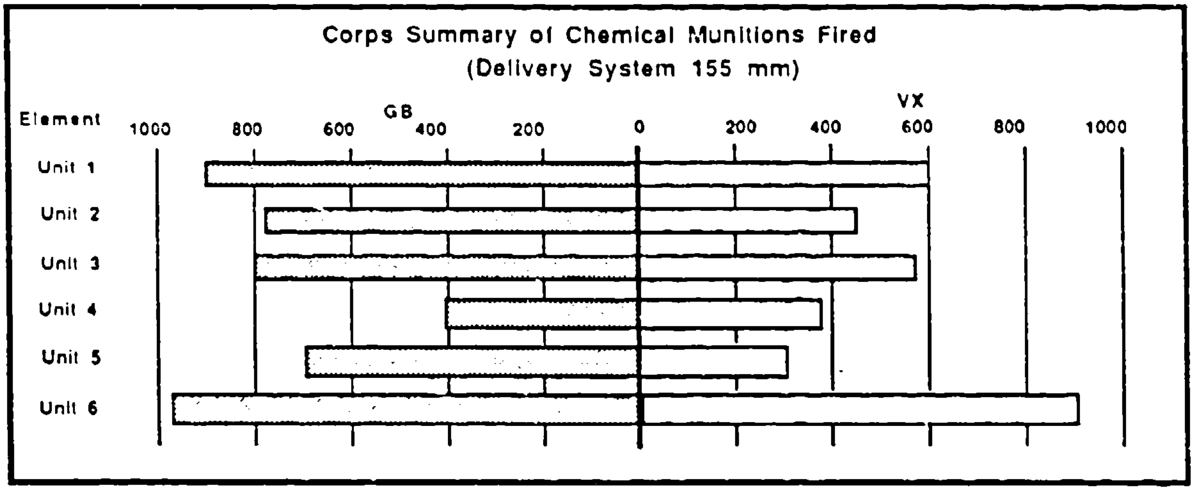


Figure 12. Sliding bar graph.

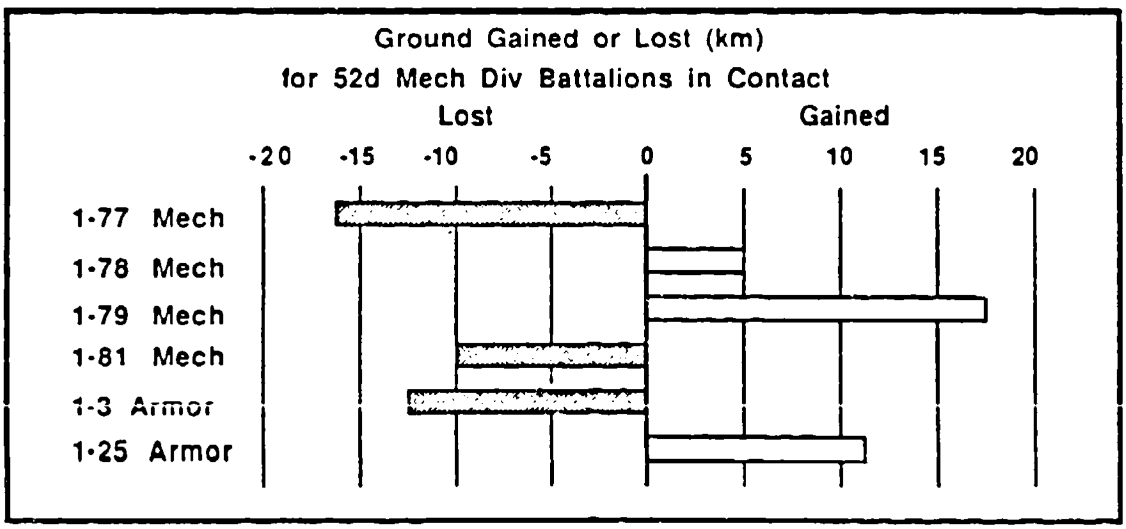


Figure 13. Deviation-bar graph.

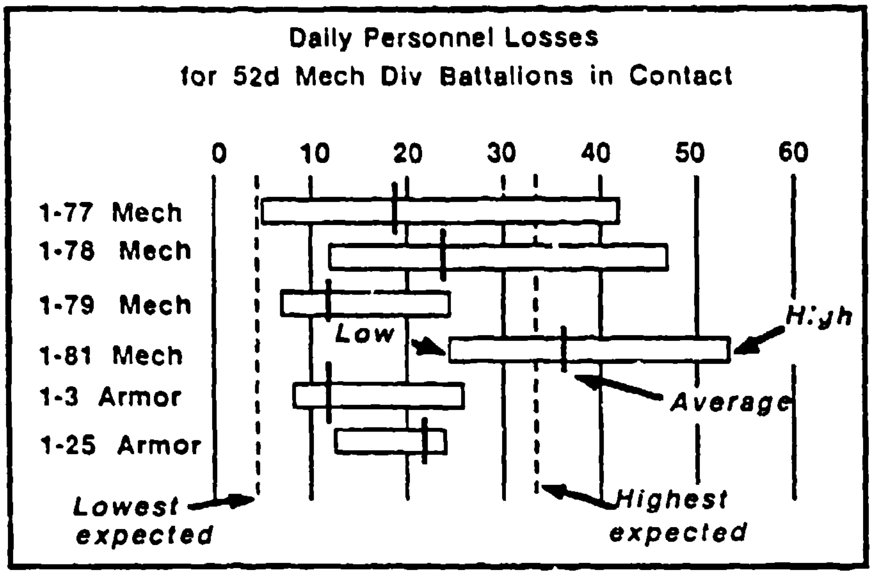


Figure 14. Range-bar graph.

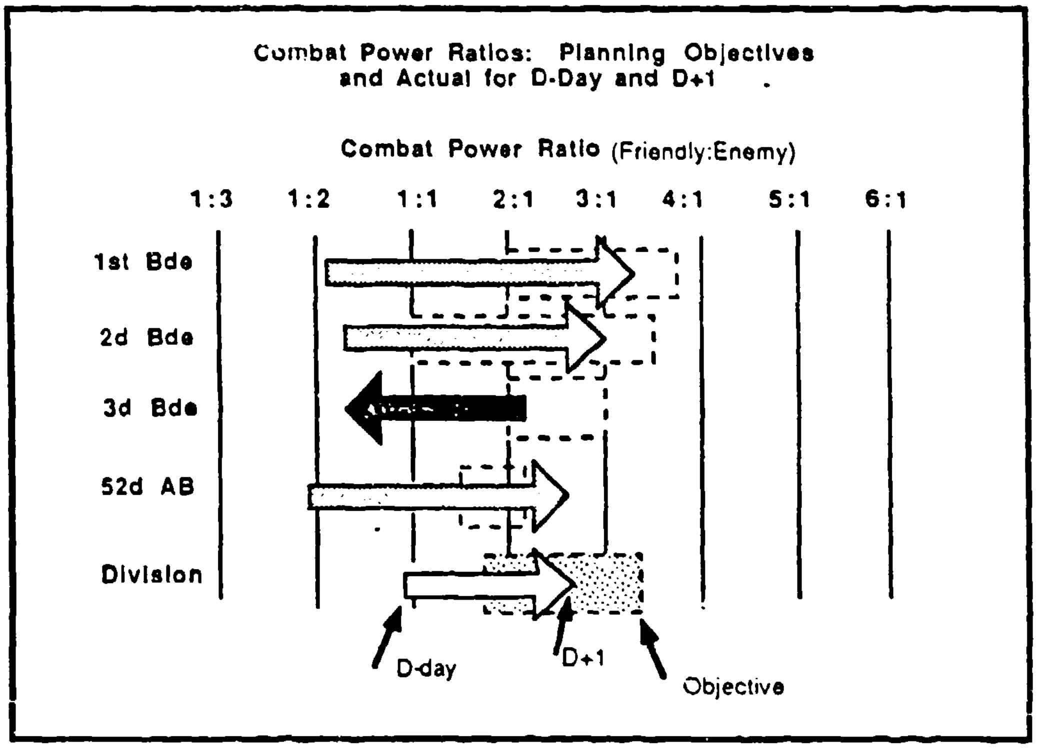


Figure 15. Change bar graph.

2.5.1.2.1. Period data. Use column graphs to portray period data rather than point data. For example, a column graph can be used effectively to show data of activities or events that occur during a period of time (such as the total distance advanced on the battlefield during Phase I of the battle), but is less effective in showing data that indicate status on a given date (such as distance advanced on the battlefield as of 2 March).

a. Point data may be shown as column graphs. However, point data can usually be represented better by curve and arithmetic line graphs or surface graphs; because these graphic forms better facilitate the analysis of point data. For example, curve graphs effectively can show trends, projections, forecasts and other estimates that are important for analyzing point data. Trend lines or other projections superimposed on a column chart usually clutter the graphic and make it more difficult to read.

See Curve and arithmetic line graphs; Surface graphs.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.2.2. Emphasize amounts or contrasts. Column graphs make a stronger presentation of the same data than curve graphs when a few data points are plotted. For example, the discreteness, vertical extension and width of the columns provide greater emphasis in showing amount of growth or development than do curves. Also, consider using the column graph rather than the curve graph when it is important to provide greater contrasts in portraying amounts in two or three short time series (e.g., a comparison of losses for Phase I and Phase II of the battle).

See 2.5.1.2.4. Grouped-column graph.
DA PAM 325-10 (1966).

2.5.1.2.3. Fluctuation in time series. Use the column graph rather than the curve graph to show time series data that fluctuates very sharply and are few in number (e.g., expenditures that vary monthly from high to low for the first quarter of a fiscal year).

DA PAM 325-10 (1966).

2.5.1.2.4. Alternative formats. Use alternative graphic formats to present a long series of data with a great many plotting points, to show numerous components of totals and when several series of data must be compared.

See 2.5.2. Curve and arithmetic line graphs; 2.5.3. Surface graphs.
DA Pam 325-10 (1966); Schmid and Schmid (1979).

2.5.1.2.2. Construction. Column graphs can be difficult to design effectively. Use these guidelines to design column graphs.

2.5.1.2.2.1. Grid. Use a grid with horizontal grid lines to present a column graph.

See 2.3.2. Grid.
Schmid and Schmid (1979).

2.5.1.2.2.2. Scale. The vertical scale of a column graph should always begin with zero and cover the range of the data to be plotted.

2.5.1.2.2.3. Spacing and width. The columns should be of uniform width and evenly spaced. Spacing between columns may vary from one-half to the same width as the columns.

See 2.5.1.1.1.4. Spacing and Width; 2.5.1.2.2.4. Connected columns; 2.5.1.2.2.5. Overlapping columns. Schmid and Schmid (1979).

2.5.1.2.2.4. Connected columns. When many columns must be plotted, use connected columns to save space and to avoid using very narrow columns. However, do not use connected columns to plot a very long time series (e.g., when data for 3 or more years are plotted by months); use an alternative format (e.g., step curve surface graph).

See Figure 16.
DA PAM 325-10 (1966, p. 91).

2.5.1.2.2.5. Overlapping columns (or bars). Avoid using overlapping columns or bars as possible to do so. The major purpose of overlapping columns or bars is to save space or to facilitate comparisons. Because the height of a bar graph is more flexible than the width of a column chart, overlapping in bar graphs can usually be circumvented by increasing the height of the graph. Use overlapping in column graphs only when each of the front set of columns is shorter than the back set.

a. Overlap the columns by one half the column width, and separate pairs by no less than one half the column width. However, with a larger number of columns it may be necessary to overlap by two thirds the column width.

b. Avoid overlapping columns that are subdivided into three or more parts, because the selection of matching shadings will be difficult. However, color can be used effectively as a part of the shading scheme when more complex subdivided columns must be overlapped, (e.g. background columns of blue could be shaded with same series of patterns as the overlapping columns, portrayed in an achromatic hue).

See Figure 16.
See 2.5.1.1.6. Grouped-bar graph; 2.5.1.2.4. Grouped-column graph; 2.4.6.1.2. Critical distinctions.
DA PAM 325-10 (1966).

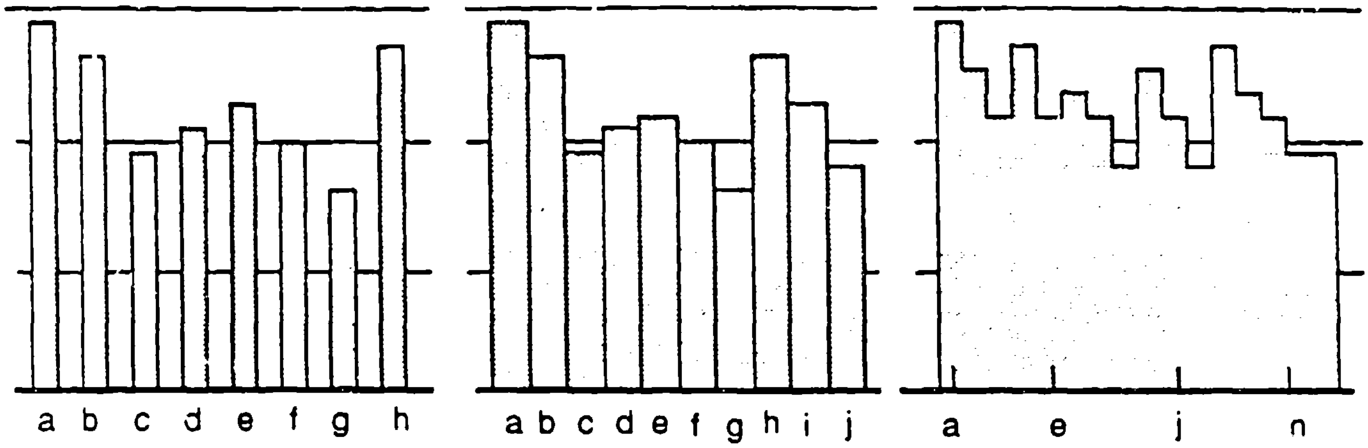
2.5.1.2.2.6. Breaking a column. Columns should not be broken, except for extreme values.

See 2.5.1.1.1.6. Breaking a bar (or column).
DA PAM 325-10 (1966).

2.5.1.2.2.7. Shading. Use shading or cross-hatching patterns to differentiate the categories of data plotted. Select patterns that do not produce adverse visual effects. Color may be used to provide emphasis or it may be used for specialized purposes. Do not use outline columns, because outline columns will not provide adequate contrast with the background of the display surface. Black and white should not be used for standard purposes and their use generally should be restricted to small areas.

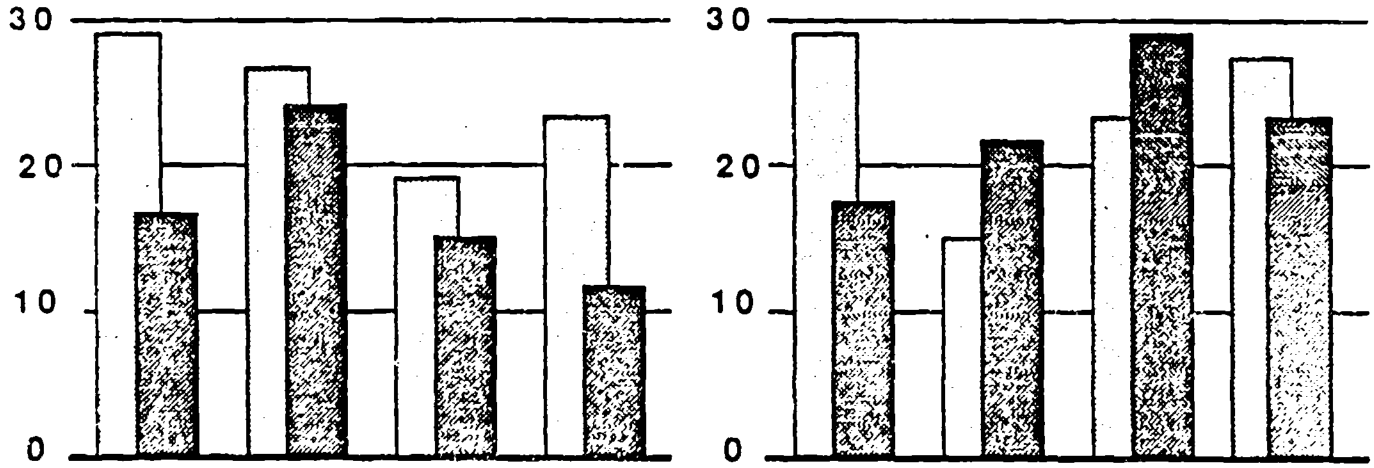
See 2.5.1.1.1.8. Shading; 2.4.6. Color coding; 2.4.7. Texture coding.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.2.3. Simple column graph. This column graph is effective for showing a single time series (e.g., procurements for January through December). The simple column graph consists of a series of vertical bars each of which extend from the horizontal scale to a plotted point.



a. b. c.

Connected columns. Connect columns (as in b. and c.) to allow wider columns or to allow more columns (than in a.).



d. e.

Overlapping columns. Columns can be overlapped when the front set of columns is shorter than the back set (as in d.) A series of columns that cross should NOT be overlapped (as in e.)

Figure 16. Illustration of the use and construction of connected and overlapping columns.

a. Under no circumstances should the horizontal scale of a simple column graph be omitted.

b. The vertical scale should always begin with zero, should cover the range of the data to be plotted, and should have horizontal grid lines that continues across the width of the graph.

c. It is common practice to use a single shading for all the columns; however, other shading or cross-hatching patterns may also be appropriate in some instances (e.g., to distinguish a column of a different category or to achieve consistency with another display that plots the same data).

See Figure 17.
See 2.5.1.2.2.1. Grid; 2.5.1.2.2.7. Shading.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.2.4. Grouped-column graph. This graph is similar to the grouped bar graph and can be used to compare two to three series of data or different categories of data in the same series. The grouped-column graph is most effective for a series of data that differ in level, in trend or by condition or classification.

a. The spacing between sets of columns should be at least as wide as a column.

b. The columns in a single group may be connected, overlapped or separated by a small space.

c. The sets of columns should have shadings that provide adequate contrast with one another and with the background of the display surface.

See 2.5.1.2.2.4. Connected columns; 2.5.1.2.2.5. Overlappping columns (or bars); 2.4.7. Texture coding.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.1.2.5. Subdivided-column graph. This graph is used to show the size of the component parts of a series of totals. It is similar to the subdivided-bar graph and serves similar purposes as the subdivided surface graph. The scale may be calibrated in either absolute numbers or percentages.

a. It is difficult to compare and identify individual segments when vertical columns are partitioned into a large number of segments. The subdivided-column graph is best used to show a series of totals that have three or four component parts. When a large number of component parts must be presented, use the subdivided surface graph.

b. Use the subdivided column graph rather than the subdivided surface graph when the plotted values fluctuate sharply from one period to the next. The subdivided column graph can be used to show the distribution of battle losses (e.g. wounded in action, missing in action, killed in action) that may fluctuate sharply during the various phases of a battle.

c. Use appropriate shading and cross-hatching patterns to differentiate the segments of the columns. When the patterns cannot be labeled within the grid, use a key or legend.

See 2.5.3.6. Subdivided or multiple-strata surface graph; 2.3.4. Labels; 2.3.5. Key or legend.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.! ˜. Deviation column graph. This type of column graph and its variant, the gros: net deviation column graph, are similar to bilateral bar graphs. The deviation column graph shows the differences between two series. It can be used effectively to present net gains and

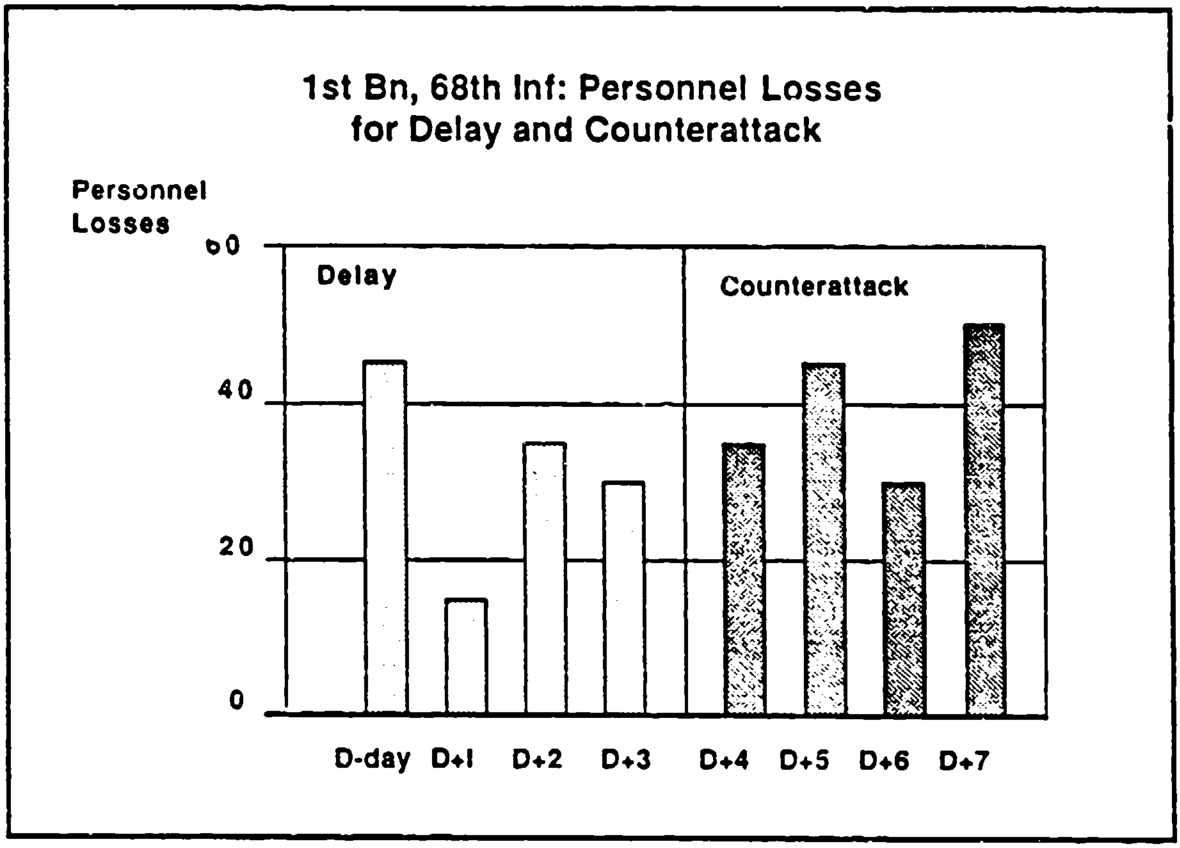


Figure 17. Simple column graph.

losses, to show increases and decreases, to show how results varied from an estimate or requirement, and to show other plus-or-minus differences.

a. Columns extend either above or below a referent line, but not in both directions.

b. By convention, positive values are plotted above the referent line and negative values below the referent line.

c. The use of diagonal lines to connect segments in adjoining columns should be avoided. Diagonal lines used in this way generally do not help to interpret the graph but rather distract from its clarity.

See 2.5.1.1.7. Bilateral bar graphs; 2.5.1.2.7. Gross and net-deviation column graph; 2.5.3.5. Net-difference surface graph.
DA PAM 325-10 (1966, p. 53); Schmid and Schmid, 1979.

2.5.1.2.7. Gross and net deviation column graph. This graph is used to portray gross and net changes. The "net", the difference between each pair of columns, is shown as an overlapping deviation column, that appears either above or below the zero referent line.

See Figure 18.
See2.5.3.5. Net-difference surface graph.
DA PAM 325-10 (1966); Schmid and Schmid (197?).

2.5.1.2.8. Floating column graph. This type of column graph is a variation of the subdivided column graph. The total length of each column is the total of two main components, and the dividing line between the two components is used as the base line. The components usually show favorable and unfavorable attributes or conditions.

a. The floating column graph differs from the deviation colûmn graphs in that each column extends both above and below the base line.

b. The unfavorable condition is usually plotted below the base line.

See Figure 19.
DA PAM 325-10 (1966).

2.5.1.2.9. Range column graph. This graphic facilitates comparisons of minimal and maximal values plotted for different time periods. The high and low values for each time period are plotted and connected by a column to show the range of the data. The range graph can be used to show monthly, weekly, or daily fluctuations in data such as personnel strength, inventories, prices, etc.

a. Average values can be included on range graphs by using cross lines or other appropriate indicators.

b. Supplementary range information such as high and low tolerance limits, upper and lower levels of efficiency, or other top and bottom "bench" mark data may be placed on a range graph. A light dash or dot line across the entire graph is generally used.

See Figure 20.
DA PAM 325-10 (1966).

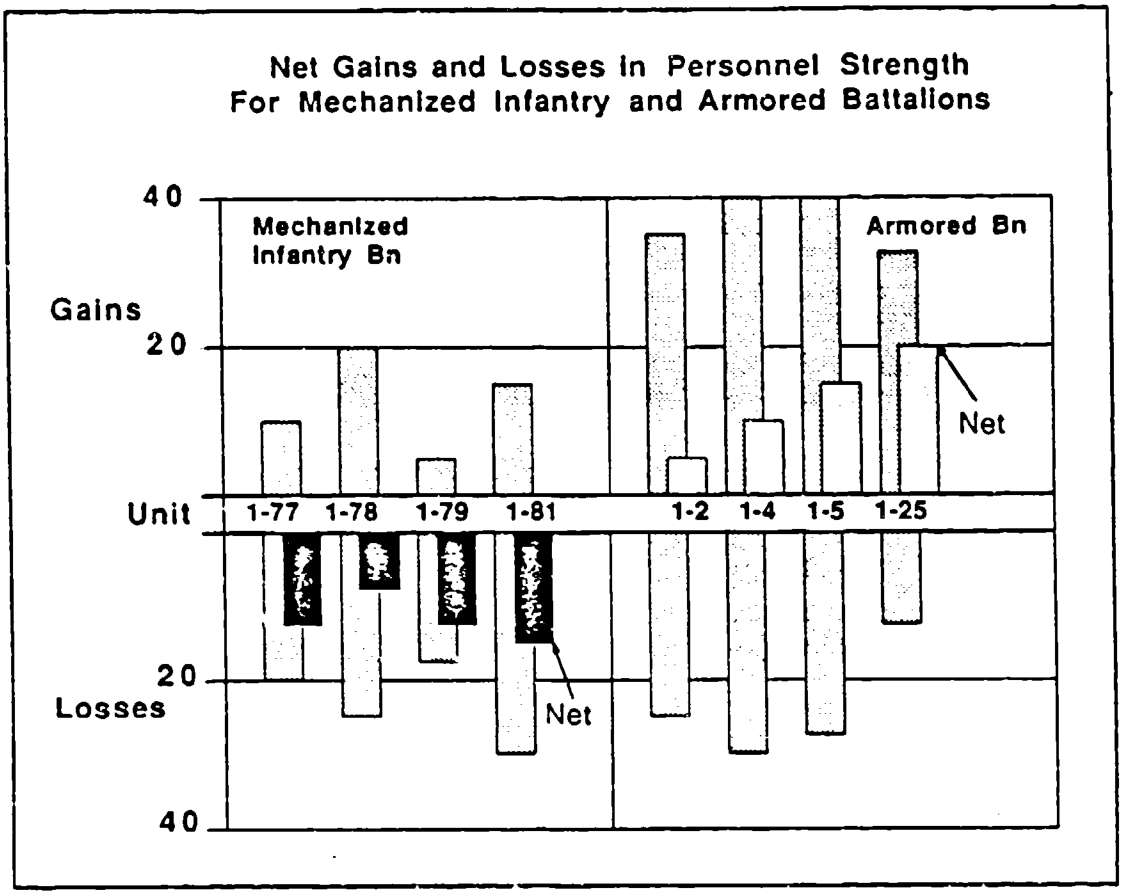


Figure 18. Gross and net deviation column graph.

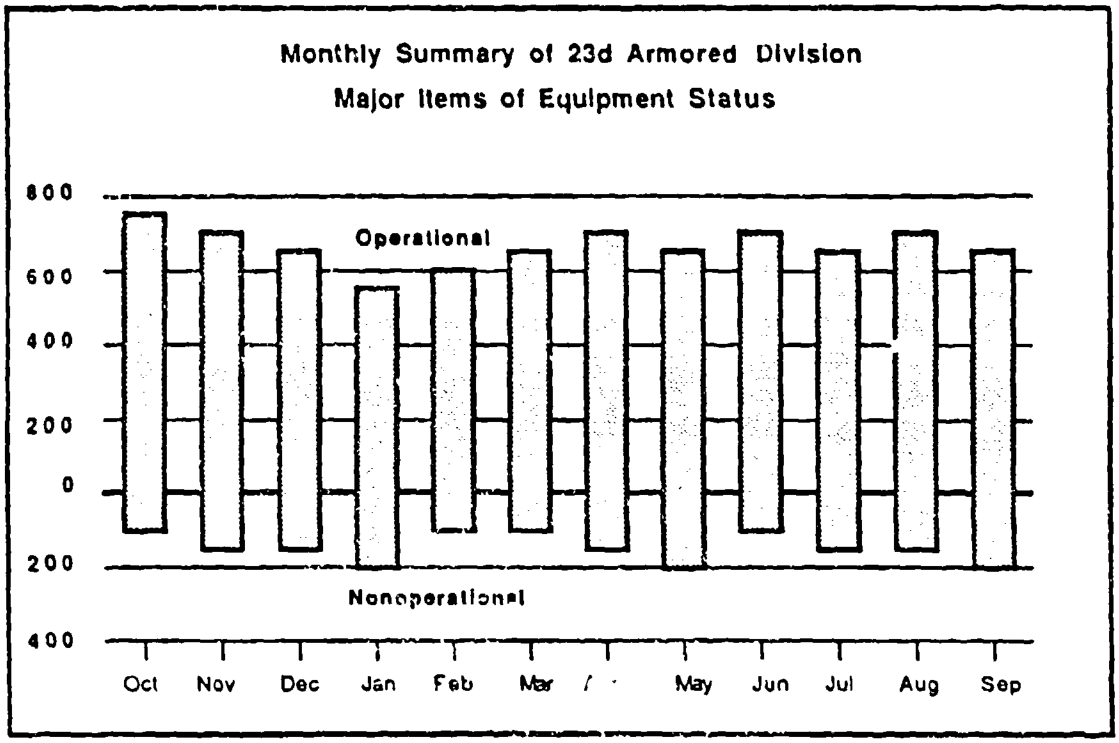


Figure 19. Floating column graph.

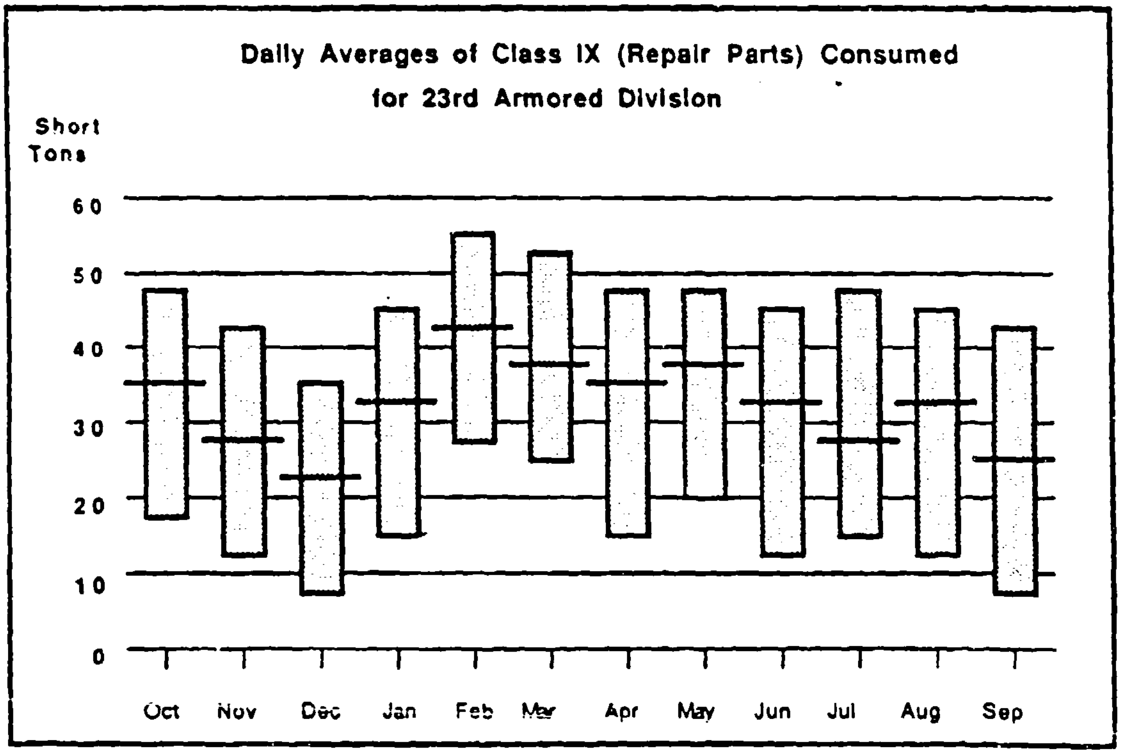


Figure 20. Range column graph.

2.5.2. Curve and arithmetic line graphs.

This general type of graphic form, called curve or arithmetic line graph, is a type of "Cartesian" coordinate graph that is derived by plotting one or more sets of data on a coordinate surface. The curve and arithmetic line graph shows relations among sets of data defined by two continuous variables. In the curve graph, data relations are summarized by a smoothed line (curve); and in the arithmetic line graph, straight line segments are used to connect successive plotting points. These graphic forms have their greatest and most significant application in the representation of time series data but are appropriate to represent any entity measured on a continuum (e.g., height, weight, temperature, area, etc.). The term "curve graph" will primarily be used herein; however, the guidelines apply to both curve and arithmetic line graphs.

a. Consider the curve graph to portray a time series when many points are plotted, several time series are compared and when emphasis is on movement or trends rather than on actual amounts.

b. The curve graph can be used effectively to show projections or forecasts.

DA PAM 325-10 (1966); Smith and Mosier (1986).

2.5.2.1. Construction.

2.5.2.1.1. Scale. Plot time or other entity (e.g., temperature, area, mission segment) considered the independent variable on the horizontal scale (X-scale); and plot amount, the dependent variable, on the vertical scale (Y-scale).

a. The number of major and intermediate scale divisions should be minimized. The scale divisions on the vertical axis should cover the entire range of the data and should be easy to read.

See 2.3.1.7. Scale axes; 2.3.1.8. Scale divisions;
Curve and arithmetic line graphs: Graphic aids-Special scales.

2.5.2.1.2. Grid.

a. Present curve and arithmetic line graphs in a fully enclosed grid that consists of both horizontal and vertical grid lines.

b. To prevent distorting the data or erroneous interpretations of the the data, break the grid when a large part of the grid is not needed. The break can be shown by a wavy line that extends horizontally across the width of the grid. The zero base line may be omitted if appropriate for the range of the relevant data.

See 2.3.2. Grid.
Schmid and Schmid (1979).

2.5.2.1.3. Multiple curves. When it is important that the user compare related curves, place multiple curves on the same graph.

a. No more than four curves or lines should be presented on the same graph.

b. When the presentation of several curves on the graph will not provide an unambiguous interpretation of the data, consider using multiple graphs, enlarging the overcrowded portion of the grid, using some other form of graphic presentation or presenting the data in a non-graphic format.

2.5.2.1.3.1. Coding. Use line coding or color coding to differentiate the curves. When curves portraying the same data are presented in a series of related displays, use line or color codes consistently.

2.5.2.1.3.2. Color. Consider using color to differentiate the curves when the graph will not be reproduced. When colored lines are reproduced, they may show only slight differences in shading tones and may not be clearly distinguishable.

See 2.5.2.2.1. Multiple slope curve graphs; 2.5.2.6.5. Multiple graphs; 2.4.6. Color coding.
DA PAM 325-10 (1966); MIL-STD 1472 5.15.3.6.5; Parrish et al. (1983); Smith & Mosier (1986); Schmid and Schmid (1979); White (1984).

2.5.2.1.4. Curve labels. When several curves are plotted on the same graph, label each curve. Labels either can be located contiguous to the curves or listed along with the curve patterns in a special key or legend. Use contiguous curve labels whenever possible to do so.

See 2.3.4. Labels; 2.5.2.1.3. Multiple curves; 2.5.2.6.5. Multiple graphs.
Schmid and Schmid (1979); Smith and Mosier (1986).

2.5.2.2. Slope curve graph. In this graphic form plotted points are connected by a smoothed line that extends from one point to the next. The slope curve graph is commonly used to display "as of" or point data, status as of specific points in time (e.g. month-end inventories, strength, unliquidated obligations). Slope curves suggest that changes from point to point are continuous and are therefore usually the best way to show data that have a "carry over" from one time to the next.

a. When fewer than four or five points are plotted, use a column graph.

See 2.5.1.2. Column graphs.
DA Pam 325-10 (1966); Schmid and Schmid (1979).

2.5.2.2.1. Multiple slope-curve graph. When it is important that the user compare related curves, use a multiple slope-curve graph, where two or more curves are presented on the same graph. A multilpe slope-curve graph can be used to show interdependent curves, such as a total and its components; independent curves, such as two or more totals, or nondependent curves, such as an actual result compared with a forecast or estimate.

a. When curves cannot be umambiguously interpreted due to criss-crossing, overlapping or other interactions, consider using two or more graphs with the same scales.

See Figure 21.
See 2.5.2.6.5. Multiple graphs.
DA Pam 325-10 (1966); Smith and Mosier (1986); White, (1984).

2.5.2.3. Step curve graph. A step curve graph is an arithmetic line graph where vertical lines are used to connect the ends of horizontal lines that are drawn through each point.

a. Use the step curve graph to show averages, or other measures that apply over periods of time.

b. A step curve graph may be used effectivlely to present data that change abruptly at irregular intervals (e.g., ammunition allotments, allocation of funds, personnel ceilings, etc.)

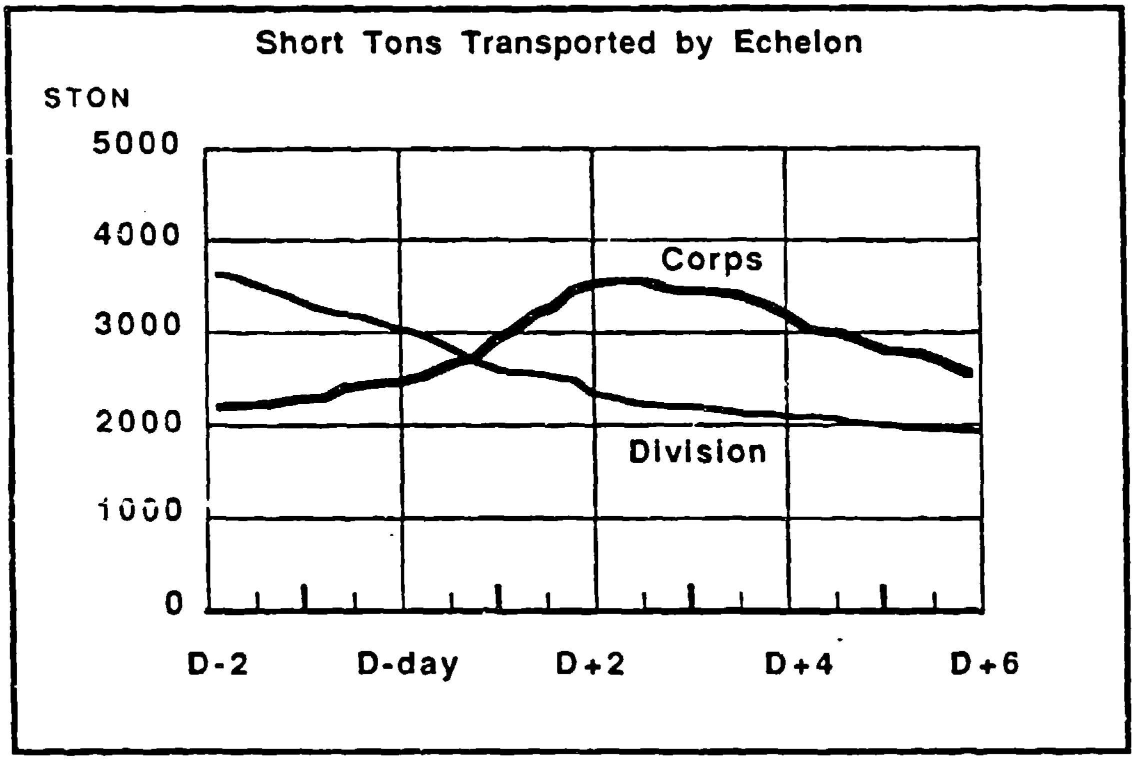


Figure 21. Multiple slope-curve graph.

c. Use the step curve graph rather than the slope curve graph to show "period" data, especially when the time series is a long one.

See 2.5.1.2. Column graphs.
DA Pam 325-10 (1966); Schmid and Schmid (1979).

2.5.2.3.1. Multiple step-curve graph. This graphic form presents two or more step curves on the same graph but should be used only in limited cases. Step curves are difficult to track if they cross. Present two or more step curves on the same graph if they do not overlap or if crossing is minimal, i.e. do not cross back and forth several times.

See Figure 22.
DA PAM 325-[illegible] (1966).

2.5.2.3.2. Cumulative curve graph. This graphic form uses either a slope or step curve to show a running total. Each point on the curve is a cumulative total, the total for the current period plus all earlier periods.

a. Use a cumulative curve graph when the cummulative total at each period can stay the same or increase but can never decrease.

b. Consider using a cumulative curve graph to compare present performance with an objective or goal.

c. Consider using multiple curves when it is important to compare cumulative totals for the same intervals for different periods.

See Figure 23.
DA PAM 325-10 (1966)

2.5.2.4. Cumulative deviation graph. This graph shows the cumulative differences or deviations at each period plotted (e.g., net gain or loss in strength, or cumulative deviation from budget or allowance). Unlike the cumulative curve graph, its curve can go down as well as up to show net changes, increases or decreases.

See Figure 24.
See 2.5.2.3.2. Cumulative curve graph.
DA Pam 325-10 (1966).

2.5.2.5. Vertical line graph. This graphic form portrays the data values of a single time series using vertical lines. The vertical lines may originate from the horizontal axis, but the graph is usually more effective when the vertical lines begin from a horizontal line through the center of the data. Consider using the vertical line graph when the user needs a display of the individual values, when the user needs to examine short-term fluctuations, or when the time series has a large number of values.

See Figure 25.
See 2.5.1.2. Column graphs; 2.5.2.3. Step curve graph.
Cleveland (1985).

2.5.2.6. Graphic aids.

2.5.2.6.1. Special scales.

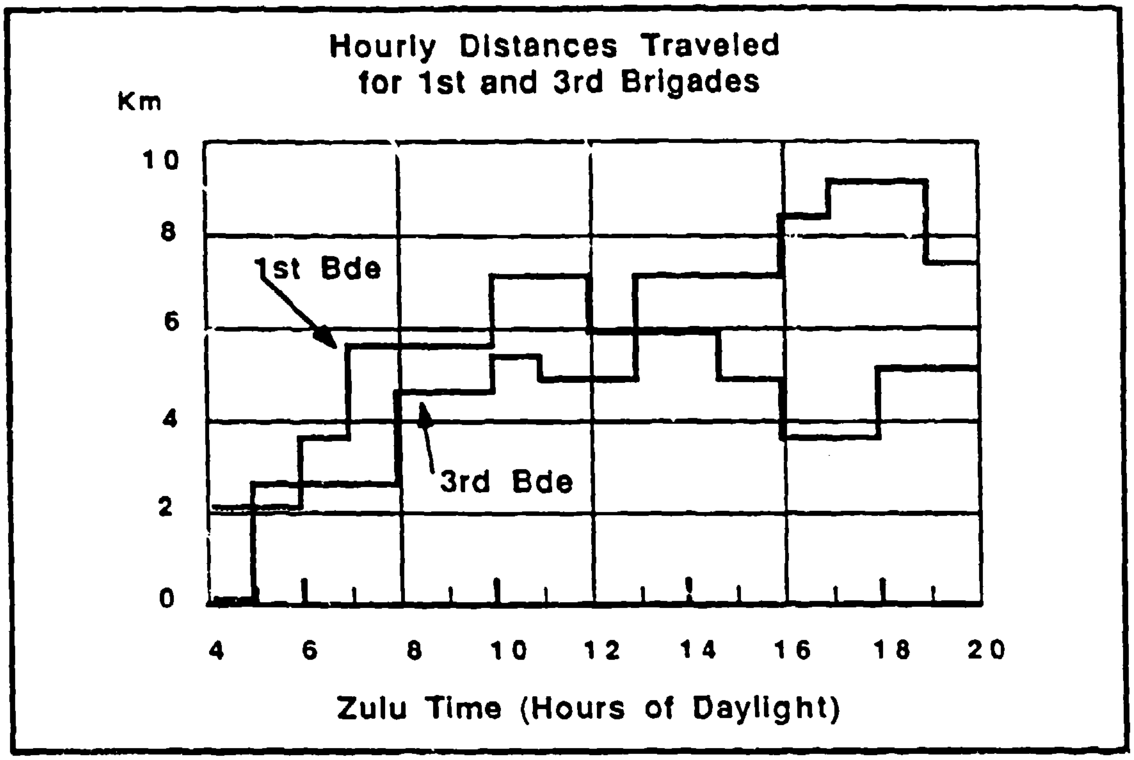


Figure 22. Multiple step-curve graph.

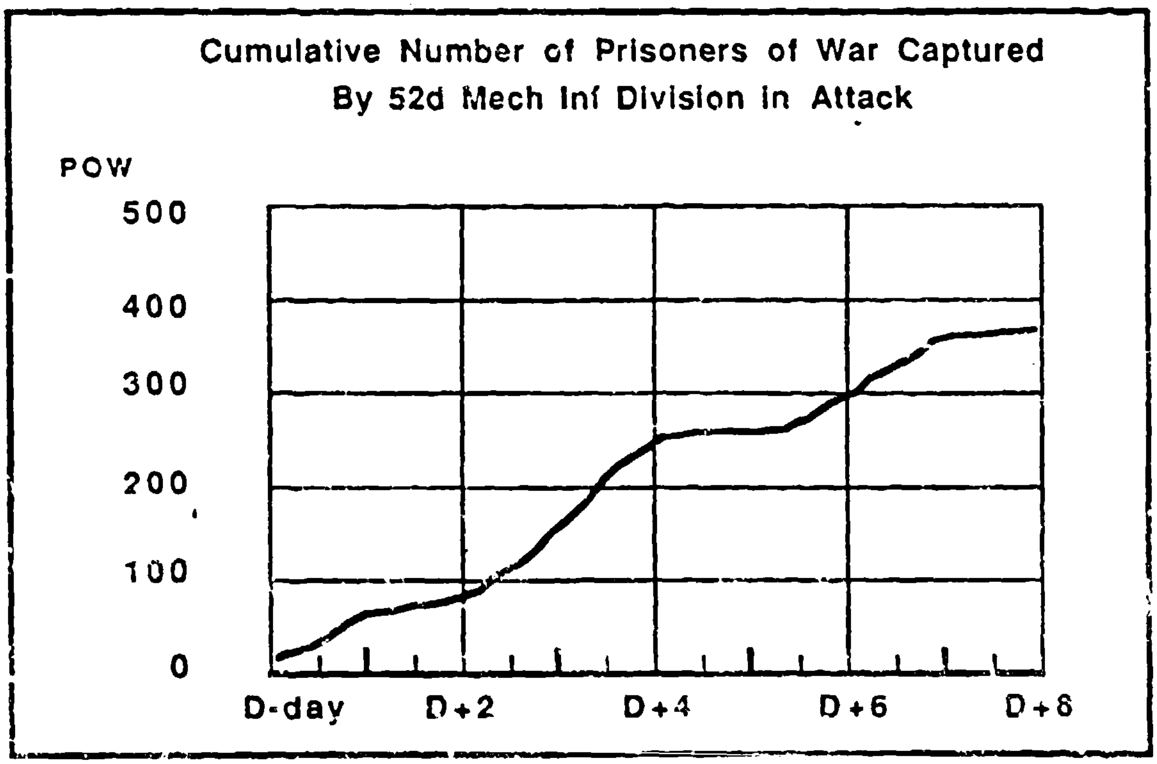


Figure 23. Cumulative curve graph.

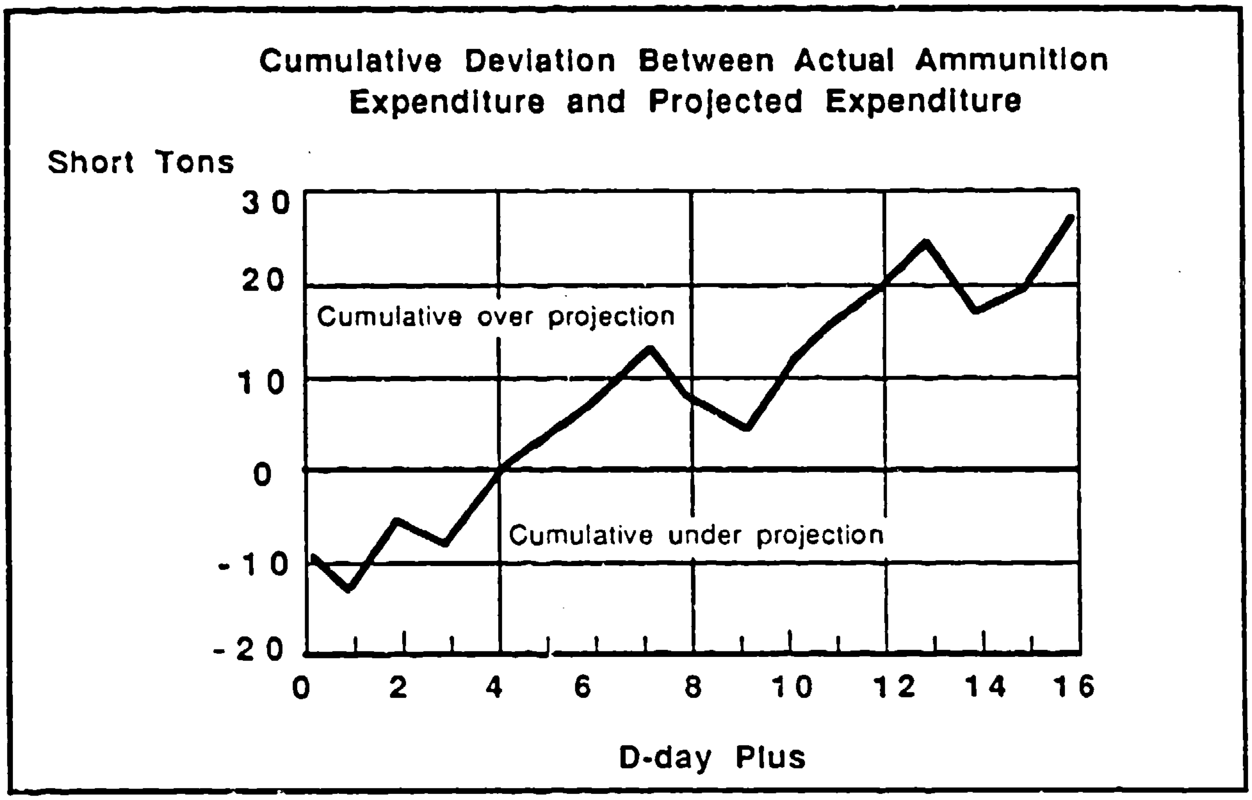


Figure 24. Cumulative deviation graph.

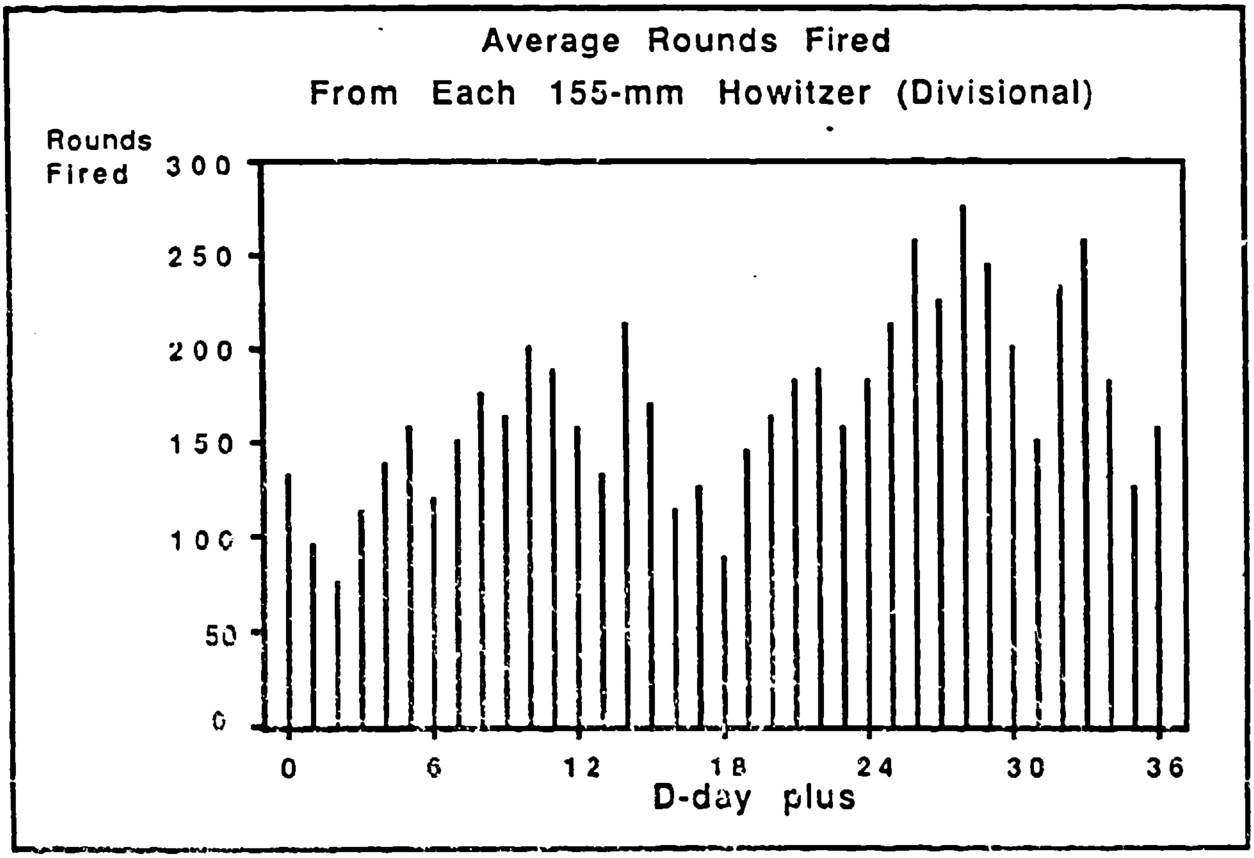


Figure 25. Vertical line graph.

2.5.2.6.1.1. Repeated time scale. An arithmetic line graph with a repeated time scale superimposes on the same grid two or more temporal series covering different periods of time. The presentation of monthly data on a 12 month time scale for different years is the most common application. Consider using a repeated time scale when it is important to bring different time series into close juxtaposition for ready comparison.

See Figure 26.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.2.6.1.2. Multiple time scale. This type of scale is similar to a repeated time scale; however, arithmetic line graphs with multiple time scales compare two or more temporal series that cover non-repeating time periods.

a. A multiple time scale can be used effectively to compare results or conditions during two historical periods (e.g. one battle campaign against another).

b. Multiple time scales are disadvantaged because they are difficult to design. The matching of time periods is the main design problem.

See Figure 27.
See 2.5.2.6.1.1. Repeated time scale.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.2.6.1.3. Multiple amount scale. For purposes of comparison, a multiple amount scale brings into close juxtaposition 2 or more curves measured in different units or curves measured in the same unit, where the spread in the range of their values makes it difficult to compare them.

a. Users must exercise extreme caution in examining and interpreting graphs that have more than one amount scale. Users can misread them easily. Generally, the use of multiple amount scales should be avoided. As alternatives to multiple amount scales, consider converting the differing time series to a common scale of measurement (e.g. index numbers or percent of average for period) or using a semilogarithmic scale.

b. When multiple amount scales must be used, consider constructing them using the following principles to help the user read and interpret them correctly and to avoid distorting the data:

(1) Use no more than two amount scales on the same graph.

(2) Never omit the zero or other base line.

(3) Start the curves from a common base line.

(4) Space the divisions of both scales in the same manner.

See Figure 28.
See 2.5.2.6.1.7. Semilogarithmic, graph; 2.5.2.6.1.5. Index scale.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.2.6.1.4. Supplementary amount scale. This type of scale provides two kinds of measurement on a single graph. In addition to measuring variations in a series of data (common to all curve graphs), a graph with a supplementary amount scale also measures the size of the series

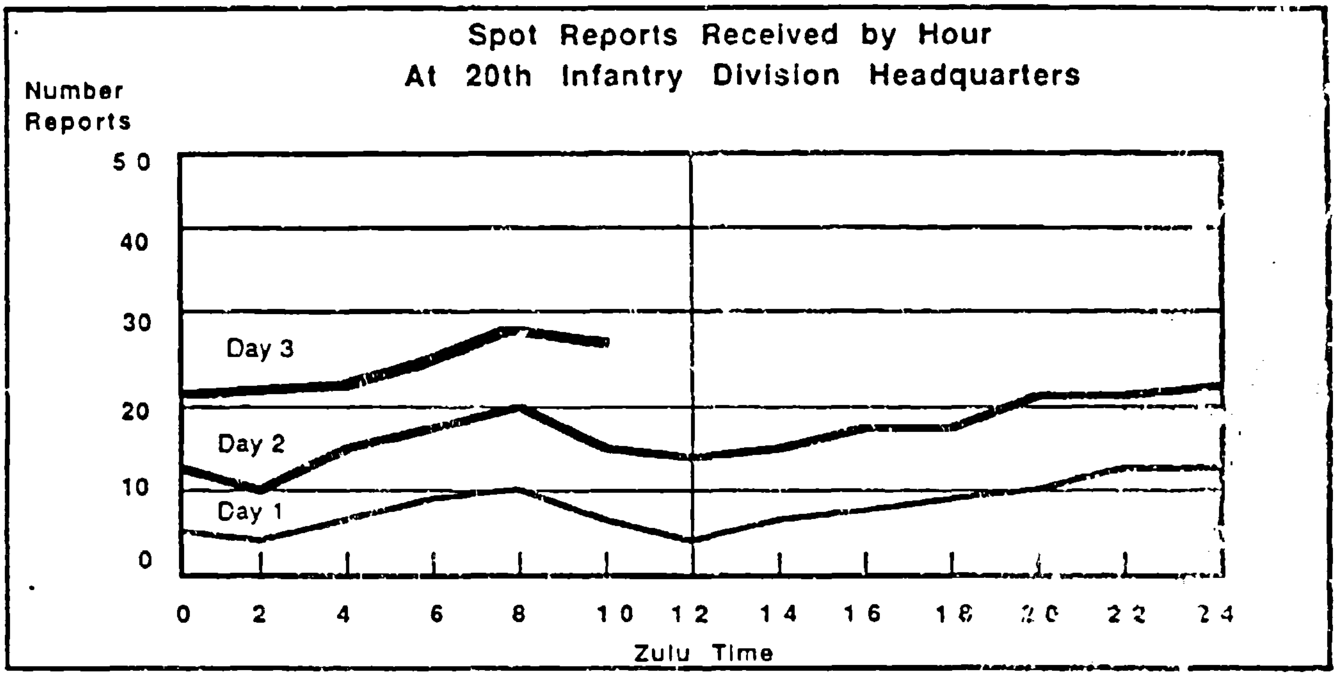


Figure 26. Repeated time-scale graph.

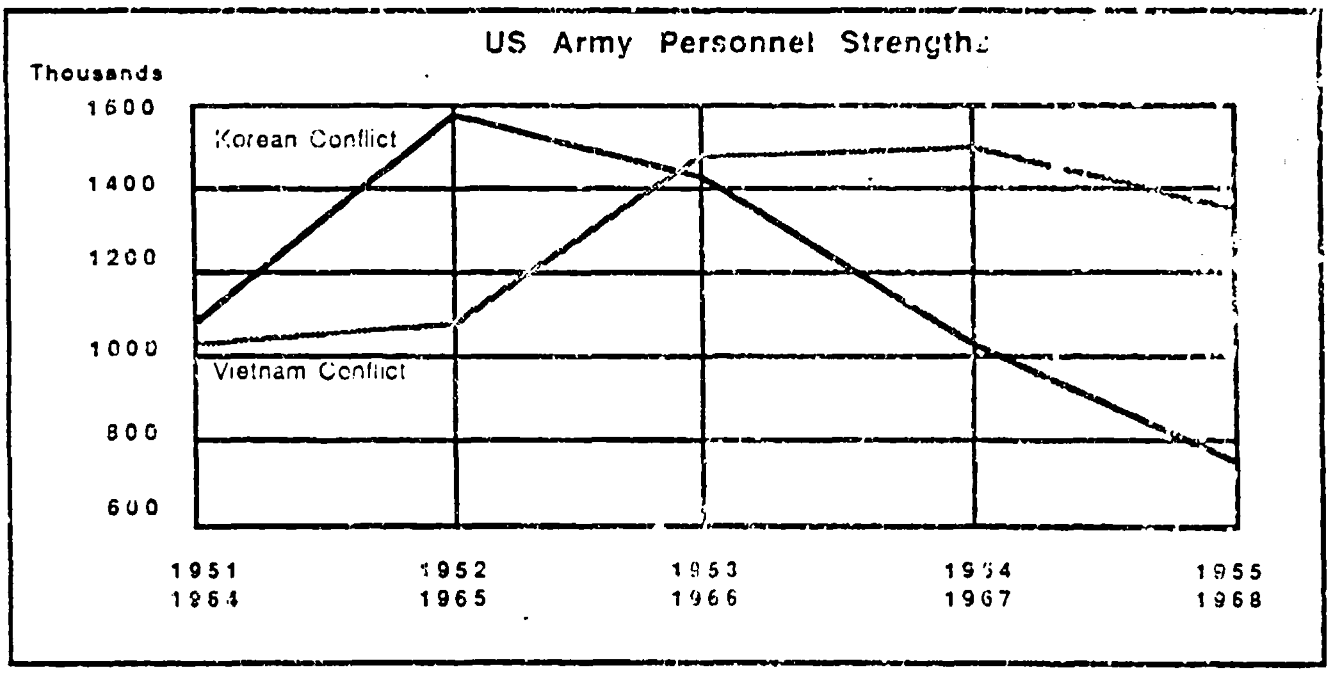


Figure 27. Multiple time-scale graph.

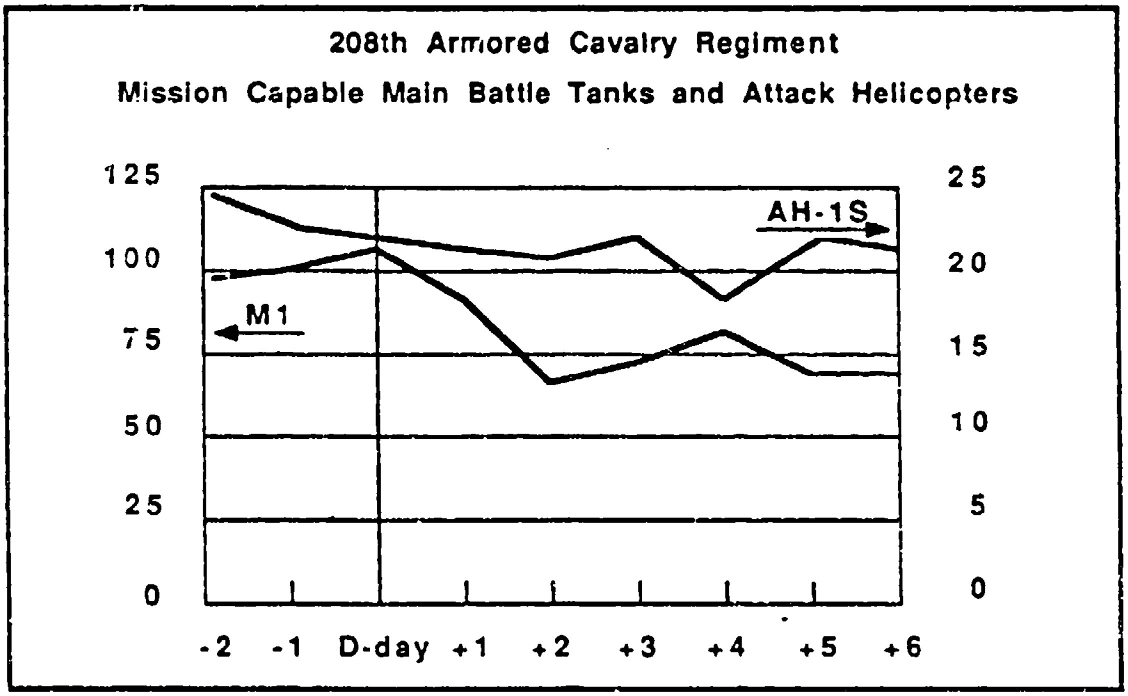


Figure 28. Multiple amount-scale format.

in relation to another series (e.g., a curve measuring officer strength plotted against a series of supplementary curves that measure 6, 9, 12 and 15 percent of total military strength).

a. Supplementary amount scales can be used effectively to portray data for any item in terms of actual and permitted levels, such as line items from a Table of Distribution and Allowance.

See Figure 29.
DA PAM 325-10 (1966).

2.5.2.6.1.5. Index-scale. An index scale shows data that have been converted into percentages of a base value. While index scales are used primarily to show composite data, they can be used for comparing two or more series of data that are measured in different units (e.g.,workload and strength) or in different size units (e.g., a total and one of its components).

a. Generally, the comparisons shown on a graph that uses an index scale can be shown clearer if presented as simple percentage differences. An exception is standard economic indexes such as price and wage indexes.

DA PAM 325-10 (1966).

2.5.2.6.1.6. Logarithmic amount scales. On a logarithmic scale equal distances represent equal ratios and on an arithmetic scale equal distances represent equal amounts. When a scale is ruled logarithmically, relative changes can be represented accurately, and the rate of change is emphasized. Arithmetic scales emphasize the absolute amounts of change.

a. Because the characteristics of logarithmic scales are not understood widely, they are recommended only for users who are familiar with them.

b. Logarithmic scales cannot be used to show zero or minus (negative) figures.

See 2.3.1.4. Logarithmic scales.
DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.2.6.1.7. Semilogarithmic graph. Line graphs that use semilogarithmic scaling have both a logarithmic scale (the vertical axis) and an arithmetic scale (the horizontal axis). This type of graph is also called a ratio graph.

a. Consider using a semilogarithmic graph when it is important to represent relative changes accurately, especially when there is a wide range in the values or sizes of the time series compared.

b. Arithmetic scales may portray changes accurately if the quantities compared are approximately the same value or size. However, the wider the range of the arithmetic scale (e.g. 0 to 9,000,000) the greater the division between actual and relative changes.

c. A logarithmic amount scale can be used to compare relatively small numbers with large ones without giving the user misleading or inaccurate impressions of the data.

d. Consider using a semilograithmic scale to show the mathematical projection of trends for special kinds of data and time series analysis, only.

e. Consider using a semilogarithmic scale to compare relative changes of a single series of data at different times, or of two or more series at the same time.

DA PAM 325-10 (1966); Schmid and Schmid (1979).

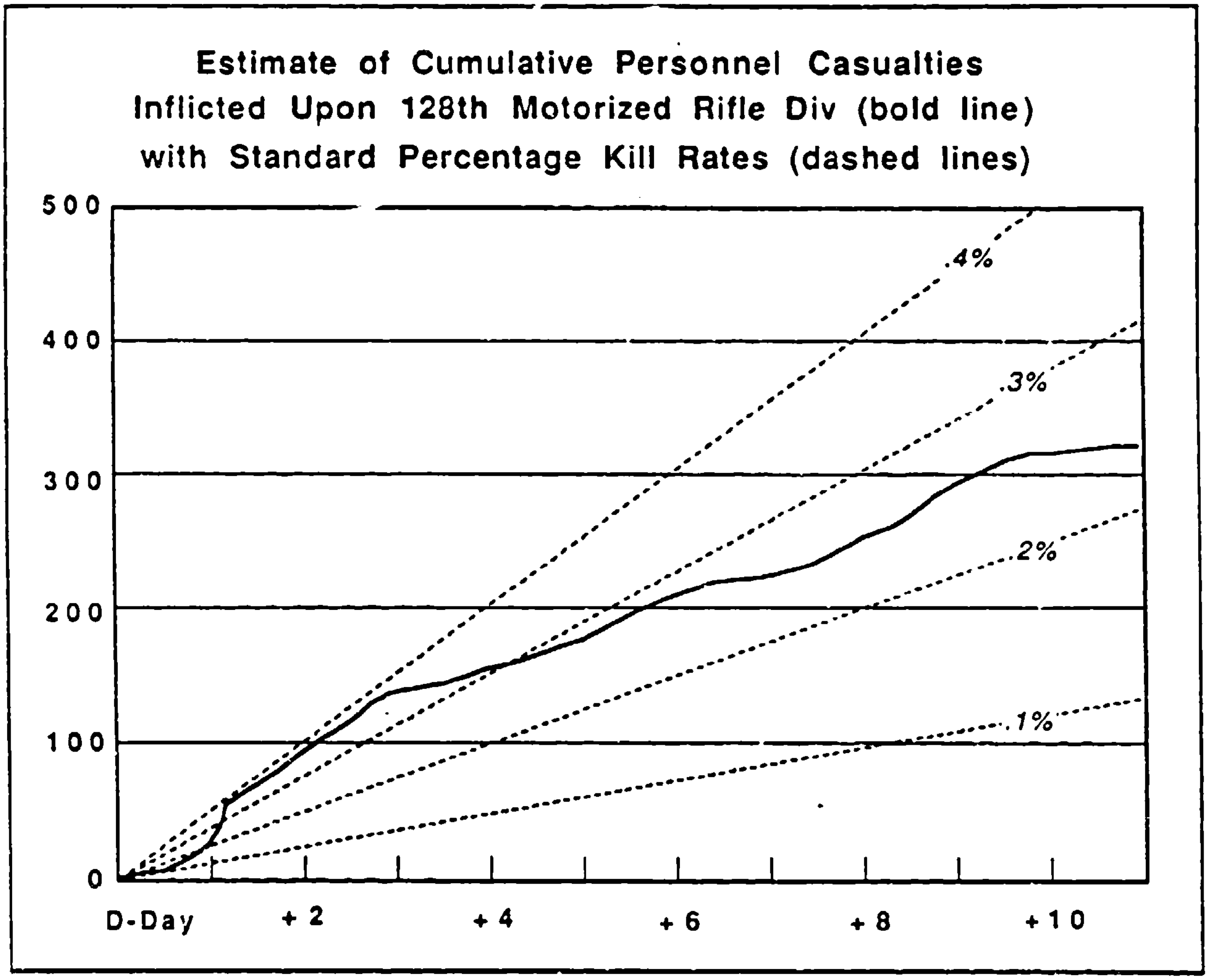


Figure 29. Supplementary amount-scale graph.

2.5.2.6.1.8. Logarithmic graphs. Line graphs that have logarithmic scales for both the vertical and horitonzal scales are called logarithmic graphs, learning curves or progress curves. These graphs are useful for studying certain production quantity-cost relations, such as those for aircraft and missile items.

DA PAM 325-10 (1966).

2.5.2.6.1.9. Multiple-log graph. A line graph that consists of a multiple-log amount scale has two vertical scales that are ruled logarithmically and a horizontal scale that is ruled arithmetically. A multiple-log amount scale permits a comparison of data that are measured in different units or that are measured in the same unit but differ considerably in size. Consider using a multiple-log amount graph when it is important to show how the relative (percentage) changes in one series compares with relative changes in another.

See 2.5.2.6.1.3. Multiple amount scales.
DA PAM 325-10 (1966).

2.5.2.6.2. Differences of curves. When the user must compare the values of two superimposed curves with widely varying slopes, a graph of the curve differences may be provided to help the user make more accurate judgments.

Cleveland (1985).

2.5.2.6.3. Trend lines. Consider superimposing a trend line (a fitted curve) on an arithmetic line graph when it is important for the user to measure the deviations from a trend (e.g., cyclical, seasonal and irregular movements) or when it is important for the user to study the trend in the data (e.g., note effect of factors bearing on the trend; compare one trend with another; discover what effect trend movements have on cyclical flucuations; attempt to forecast the future behavior of the trend). Trend lines may be developed using an appropriate mathematical technique (e.g., simple moving average, weighted moving average, least-squares method, asymptotic growth curve, etc.).

Schmid and Schmid (1979).

2.5.2.6.4. Residuals. When the user must judge the vertical distances of points from a fitted curve or trend line, a graph of the residuals may be provided to help the user make more accurate judgments.

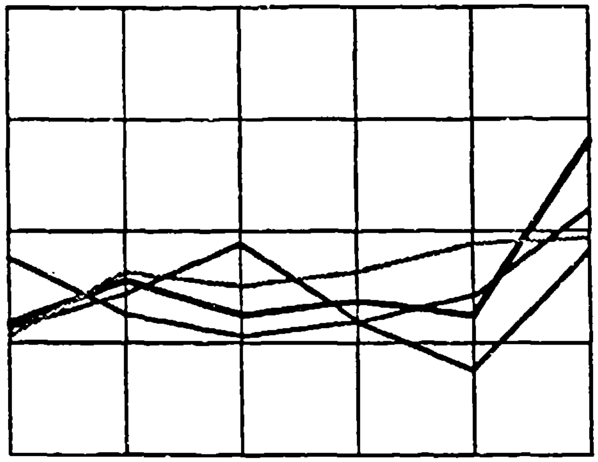
Cleveland (1985).

2.5.2.6.5. Multiple graphs. To support user interpretation of a graph that has multiple lines or curves, consider using multiple presentations. In addition to the single graph that presents the juxtaposed curves, display pairs of curves separately. Use the same scale in all graphs; and consider allowing the user to select pairs of curves for display.

See Figure 30.
See 2.5.2.2.1. Multiple slope-curve graphs.
Smith and Mosier (1986), White (1984).

2.5.3. Surface graphs.

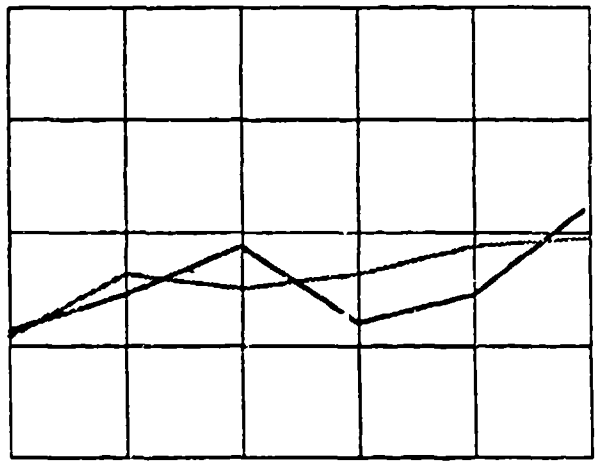
Surface graphs are essentially types of curve and arithmetic line graphs that are shaded or textured to provide greater emphasis. Specifically, a surface graph is a plot of one or more lines, curves or steps where the distances between the plotted graphic elements are filled with cross-hatching, shading or color to create strata or layers. Surface graphs can be used effectively to



a.

The four curves presented together in this multiple slope curve graph are difficult to interpret.

b.



c.

Different pairs of curves are presented in separate graphs (b. and c.) to assist the user in interpreting the multiple slope curve graph.

Figure 30. Multiple graphic format for user interpretation of multiple slope curve graphs.

portray component relations (e.g.,to portray a total and its component or to show how the component parts of a total change in importance over a span of time). However, unlike arithmetic line graphs, surface graphs cannot directly show forecasts, estimates or other projections and multi-strata surface graphs are difficult to read.

See Subdivided or multiple-strata surface graph; Subdivided or multiple-step surface graph.
DA PAM 325-10 (1966); Schmid and Schmid (1979)

2.5.3.1. Construction.

2.5.3.1.1. No broken scale. The scales of surface graphs should never be broken. Broken scales will distort the data.

DA PAM 325-10 (1966); Schmid and Schmid (1979).

2.5.3.1.2. Coding. To avoid adverse visual effects and to achieve clarity, simplicity, and ease of interpretation, the method used to differentiate the strata or stratum (e.g., cross-hatching, shading or color) should be selected judiciously.

See 2.4.6. Color Coding; 2.4.7. Texture Coding.

2.5.3.1.3. Strata labels. Each stratum label or designation should be located directly within the textured or shaded stratum it identifies. When there is insufficient space, a label may be placed outside the stratum and connected to the stratum using an arrow. However, when an arrow must cross a stratum to reach one that is unlabeled, use a key or legend to identify the strata of the surface graph.

See 2.3.5. Key or legend.
Schmid and Schmid (1979); Smith and Mosier (1986).

2.5.3.2. Simple surface or silhouette graph. This graph is a slope curve graph in which the area between the curve and the base line or other reference line is textured or shaded. It is primarily used to provide added emphasis (e.g., to make a simple growth curve look more impressive).

See Figure 31.
See 2.5.2.2. Slope Curve Graph.
PAM 325-10 (1966); Schmid and Schmid (1979)

2.5.3.3. Simple step or staircase surface graph. This graph is a step curve graph in which the area between the steps or staircases has been textured or shaded. Its uses parallel those of the step curve graph. Also, the step surface graph is similar to
a connected column graph and can be used instead of connected columns to plot a long time series (e.g., when data for 3 or more years are plotted by months).

See 2.5.2.3. Step curve graph; 2.5.1.2.2.4. Connected columns.
DA PAM 325-10 (1966).

2.5.3.4. Band surface graph. In a band surface graph the space between two curves is shaded or textured to emphasize the differences between the two curves, as well as their absolute magnitudes (e.g., to show profit margin, an increase, a decrease, a difference between cumulative expenditures and obligations). To use the band surface graph one series of data must always be greater than the other, the two series cannot cross. This graph is also a type of range graph and serves similar purposes as the range-column graph.

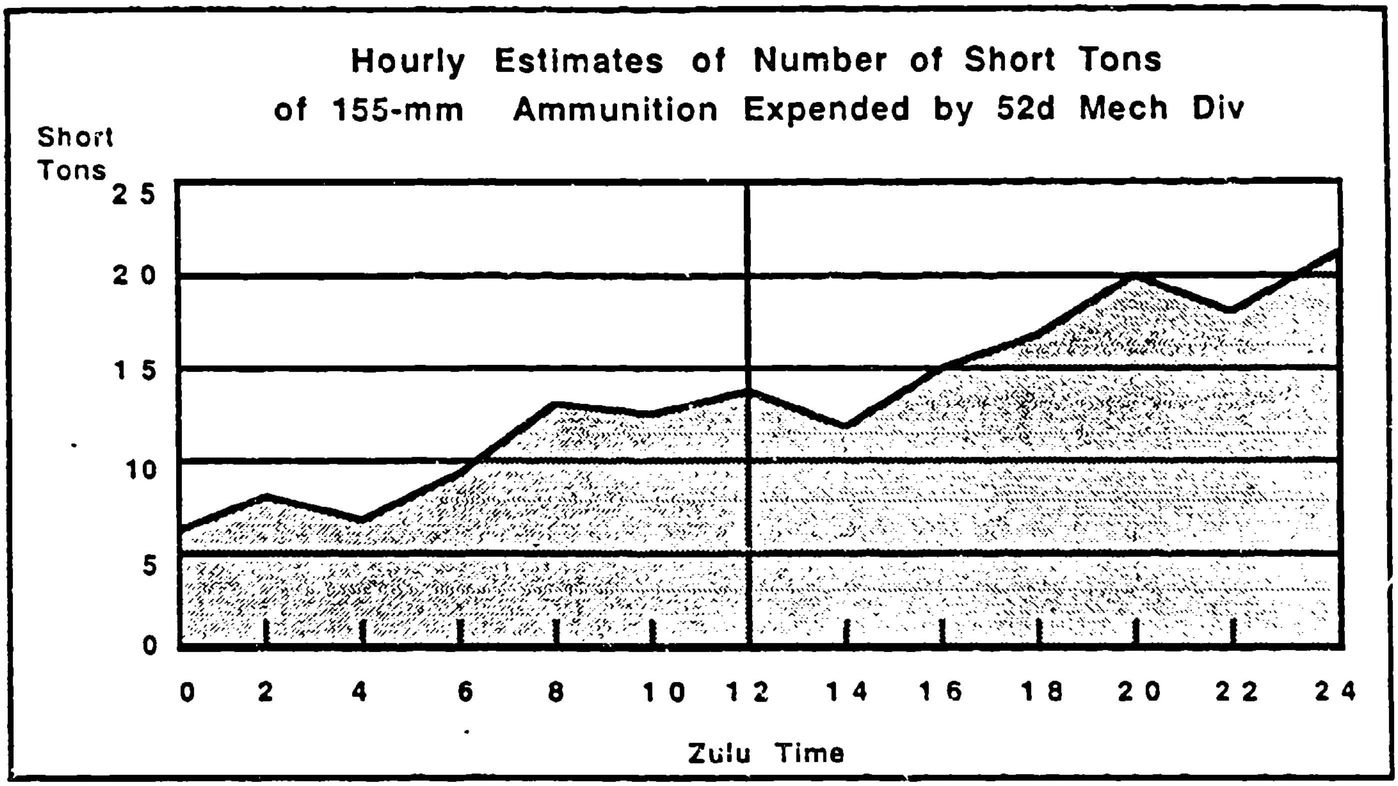


Figure 31. Simple surface or silhouette graph.

See Figure 32.
See 2.5.1.2.9. Range-column graphs.
DA PAM 325-10 (1966, p. 51); Schmid and Schmid (1979).

2.5.3.5. Net-difference surface graph. The net-difference surface graph is used to show differential changes between two series of data. Unike the band surface chart, the two curves shown can cross so the difference between them can have two meanings (e.g., net loss or net gain or other plus-or-minus differences, income and expenses, personnel accessions and separations, etc.). Contrasting shadings or textures are used to differentiate the plus-or-minus differences. The net-difference surface graph has similar uses as the deviation column graph and the gross and net-deviation column graph.

See Figure 33.
See 2.5.1.2.6. Deviation column graph; 2.5.1.2.7. Gross and net-deviation column graph.
DA Pam 325-10 (1966, 51); Schmid and Schmid (1979).

2.5.3.6. Subdivided or multiple-strata surface graph. The subdivided surface graph has similar uses as the multiple slope curve graph from which it is derived. However, this graph is used widely in statistical presentation to show how the component parts of a total change in importance over a span of time (i.e., to show trends in the distribution of the component parts over time). The data values may be expressed either in absolute numbers or percentages. Restrictions on the use and construction of the multiple-strata surface graph are described below.

Schmid and Schmid (1979); White (1984).

2.5.3.6.1. Precise comparisons. It is difficult to read the data on a surface graph and to make accurate comparisions when more than one strata is shown. Only the bottom layer and a total on a multiple-strata surface graph can be read directly from the base line. The values of the other strata are read using the distance between the plotted lines. Therefore, when a user must make precise, measurable comparisons, consider using a column graph or break up the series of layers into individual graphs keyed to the master surface graph.

2.5.3.6.2. Data that rise sharply. Do not use the multi-strata surface graph to plot data that rise sharply; use an alternative graphic format, such as a column graph. If a series of strata in a multi-strata surface graph display a sharp upward trend, an illusion may be created in the top stratum which may indicate a decrease in its width toward the end of the series. This illusion results from a tendency of the eye to interpret the width of the stratum horizontally rather than vertically.

See2.5.2.2.1. Multiple slope curve graph; 2.5.1.2. Column graphs.
Schmid and Schmid, (1979).

2.5.3.6.3. Positioning of strata. To avoid distortions in the strata of a multiple-strata surface graph, place the least variable strata at the bottom and the most variable strata at the top. An irregular component when placed at the bottom of a surface graph may distort the strata placed on top of it; and these strata may also be perceived as irregular. In cases where arranging the strata to fit the behavior of the data would be illogical given the subject of the data plotted, consider an alternative format (e.g., multiple-step surface graph, multiple slope-curve graph, or column graph).

See 2.5.3.7. Subdivided or multiple-step surface graph; 2.5.2.2.1. Multiple slope-curve graph; 2.5.1.2. Column graphs.
DA PAM 325-10 (1966); Schmid and Schmid (1979); Smith and Mosier (1986).

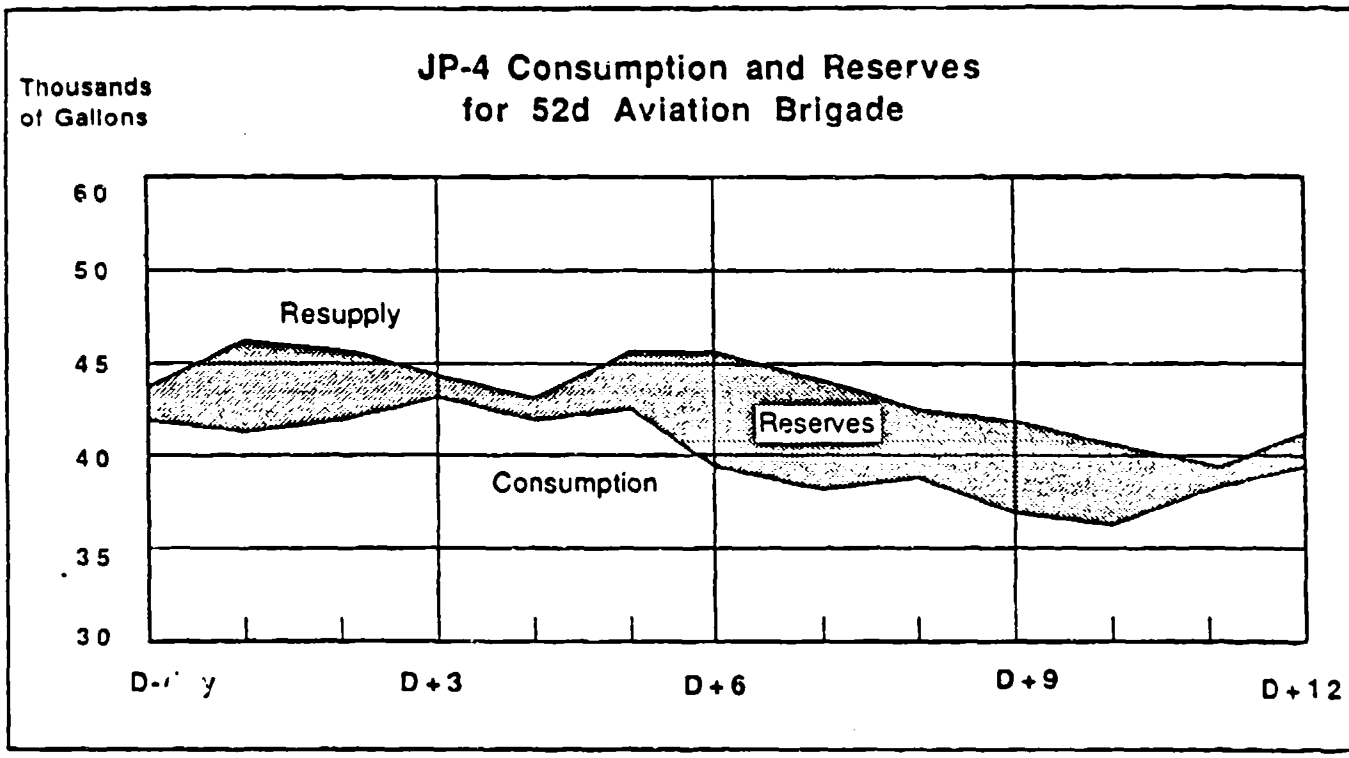


Figure 32. Band surface graph.

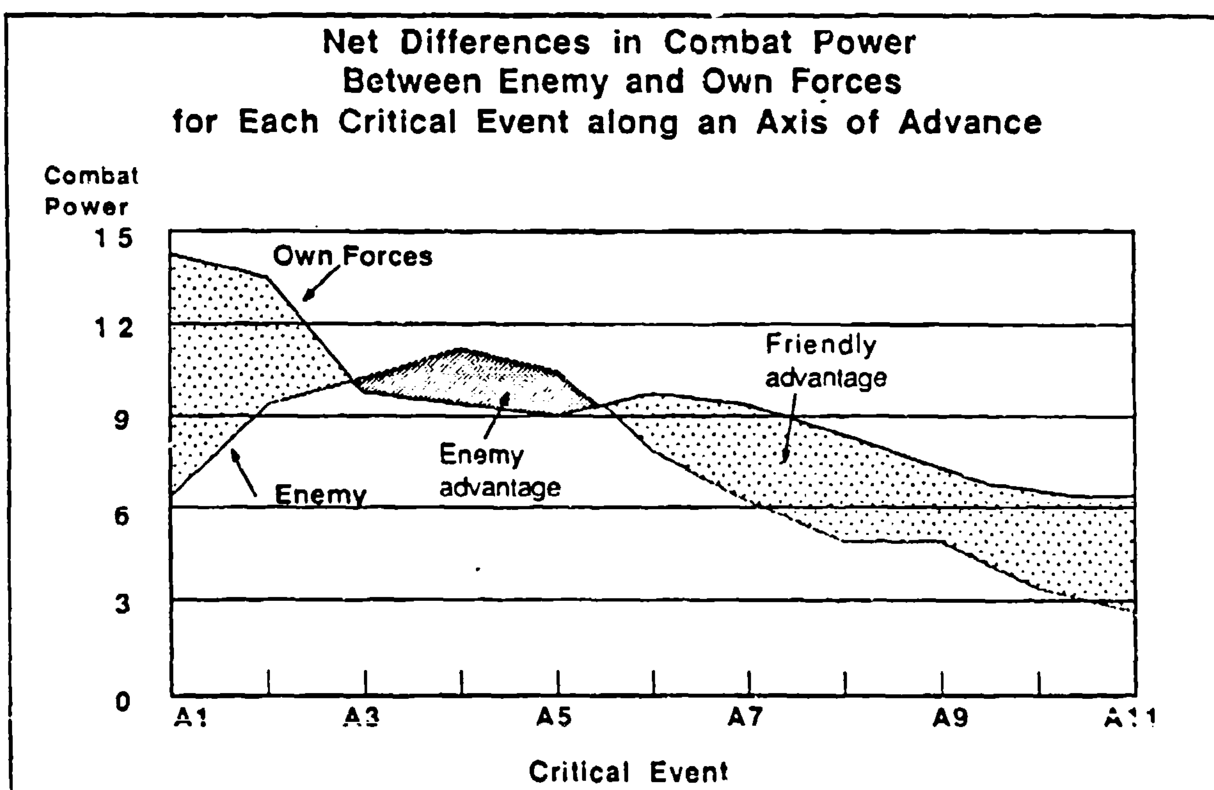


Figure 33. Net-difference surface graph.

2.5.3.7. Subdivided or multiple-step surface graph. This graph presents two or more shaded or textured step curves on the same graph. It can be used effecuvely to show "period data" as opposed to "point data," and to show averages or other composite measures that apply over periods of time. However, it is especially effective for presenting data that change abruptly at irregular intervals or move up or down at irregular intervals. The least variable strata should be placed at the bottom and the most variable strata at the top, as possible to do so.

See Figure 34.
DA PAM 325-10 (1966)

2.5.4. Pie charts. This chart, also known as a sector graph or sectogram, is a circular graphic used to display component relations, the proportion of the components to the whole. The various sectors of the circle represent component parts of an aggregate or total and show the relative distribution of quantitative data among the components or categories.

2.5.4.1. Use.

2.5.4.1.1. Number of components. Use a pie chart to portray a total that consists of no more than five components or categories.

2.5.4.1.2. Focus attention on single component. Use pie charts when it is important to focus attention on one important component or category of a total.
See Pie Chart, Construction, Sectors.

2.5.4.1.3. Subtotals. A pie chart can be used effectively when its components provide useful subtotals.

2.5.4.2. Restrictions on use.

2.5.4.2.1. Comparison of components. Generally, the use of pie charts to compare the components of a total should be avoided. Alternative graphic forms that require linear measurement should be used, when possible to do so (e.g., bar graphs, column graphs and curve and arithmetic line graphs).

a. Pie charts require estimation of angle or area. Because the eye can compare linear distances more easily and accurately than angles or areas, the component parts of a total can usually be shown more effectively in a graph using linear measurement.

2.5.4.2.2. Multiple pies. A pie chart should not be used when a comparison calls for more than one divided total. Do not use pie charts of different sizes to compare totals of different sizes.

2.5.4.2.3. Display area. When the amount of space is an important factor, consider alternative graphic forms. Pie charts require several times more space than linear comparisons and in addition, are more limited in their range of useful variations.

Cleveland (1985); DA PAM 325-10 (1966); DOD-HDBK-761A (1987); Schmid and Schmid (1979); Smith and Mosier (1986) White (1984).

2.5.4.3. Construction.

2.5.4.3.1. Sectors.

a. Arrange the sectors of a pie chart from largest to smallest, beginning with the largest sector at 12 o'clock.

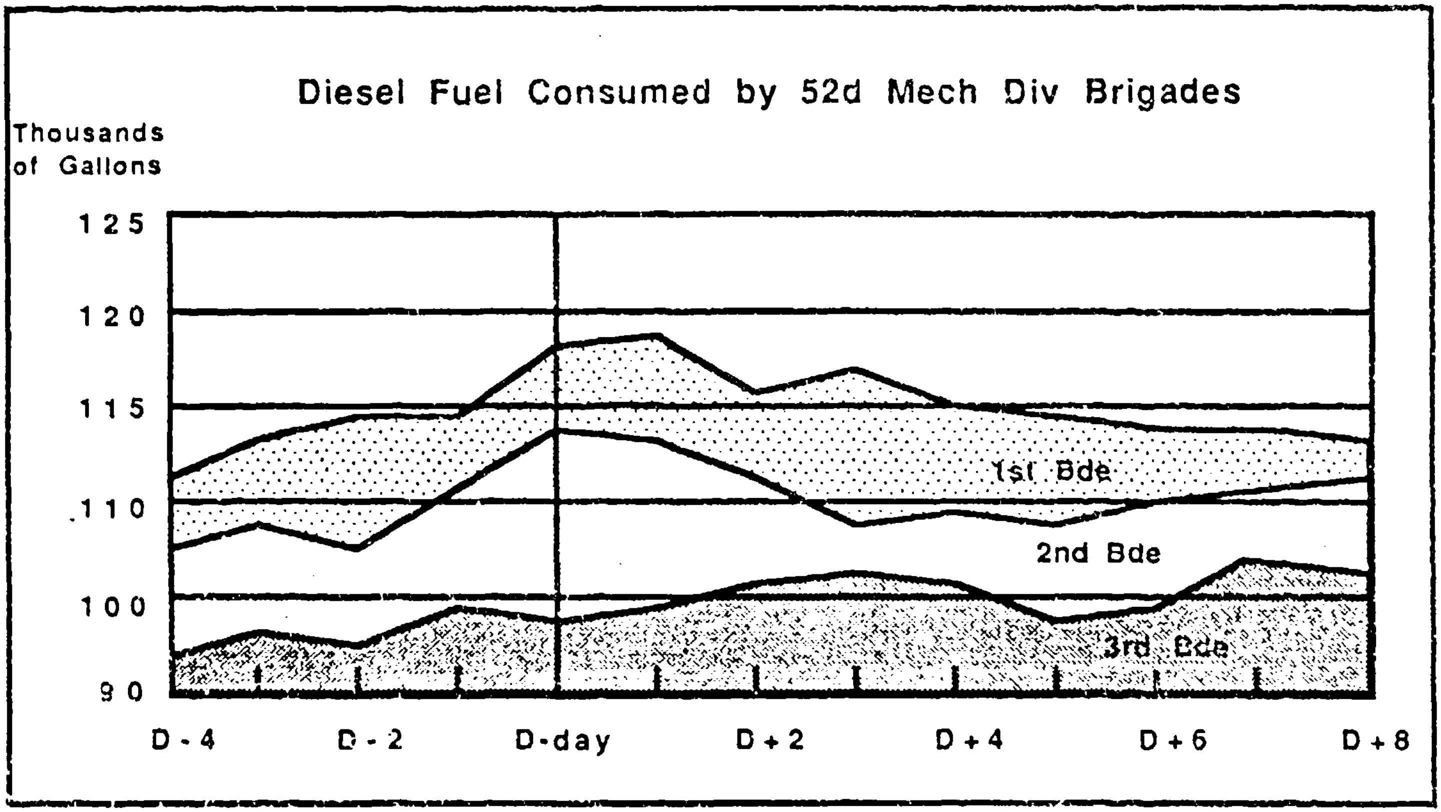


Figure 34. Subdivided or multiple-strata surface graph.

b. To differentiate the sectors, hightlight the sectors using shading coding or cross-hatching according to a density sequence from dark to light (or vice versa).

c. To emphasize a particular sector of a pie chart, consider hightlighting the sector by special hatching or shading, or by displacing the sector from the remainder of the pie chart.

d. When a sector has subcomponents, consider displacing that sector and dividing the sector into its component parts outside the pie to provide added emphasis and detail.

See Figure 35.
DA PAM 325-10 (1966); DOD-HDBK-761A (1987); Schmid and Schmid (1979); Smith and Mosier (1986); White (1984).

2.5.4.3.2. Labeling.

a. Place the labels inside the sectors if there is sufficient space; otherwise the labels should be placed in contiguous positions outside the circle usually with an arrow pointing to the appropriate sector.

b. Place the percentages or other absolute values represented by each sector directly below the identifying label.

Schmid and Schmid (1979).

2.5.5. Flow chart.

A flow chart is a diagram of facts and relations (e.g., positional, hierarchical, functional, conceptual, structural, or sequential relations). It depicts nonquantifiable relationships among persons, events, operations, processes, components, data or other entities. Process charts, organizational charts, spider charts, progress charts, time line charts, and time-and-activity charts are considered types of flow charts.

2.5.5.1. Use. Flow charts can be used effectively to present a large number of facts and relationships simply, clearly, and accurately. To avoid an extensive or somewhat involved verbal description of facts and relationships use a flow chart rather than text.

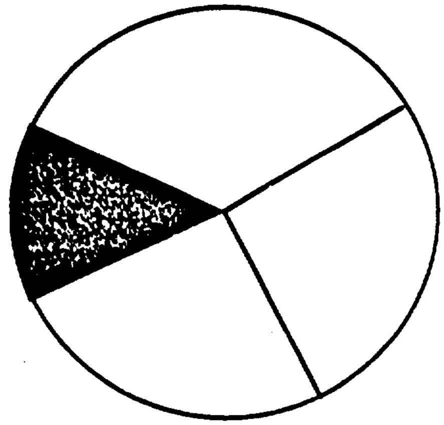
a. Use flow charts to portray sequences in processes, events and organized operations (e.g., a flow chart that shows the specific sequences of events in the concept exploration, demonstration and validation, full-scale development and production deployment phases of a weapon system).

b. Use flow charts to portray movement, lines of command in organizations, functional relationships, time stages and other subjects (e.g., a flow of income and expenditures, an organizational chart of a unit, and a time line chart of targetted allocations of time for the steps in generating and deciding upon a course of action.

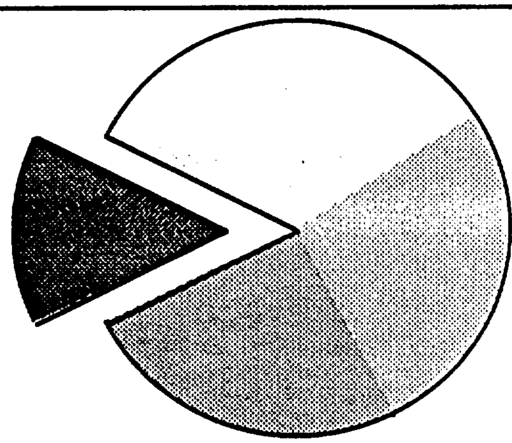
See Figure 36.
See 2.5.5.3. Process chart.
Parrish et al. (1983); Schmid and Schmid (1979); Smith and Mosier (1986); White (1984).

2.5.5.2. Construction.

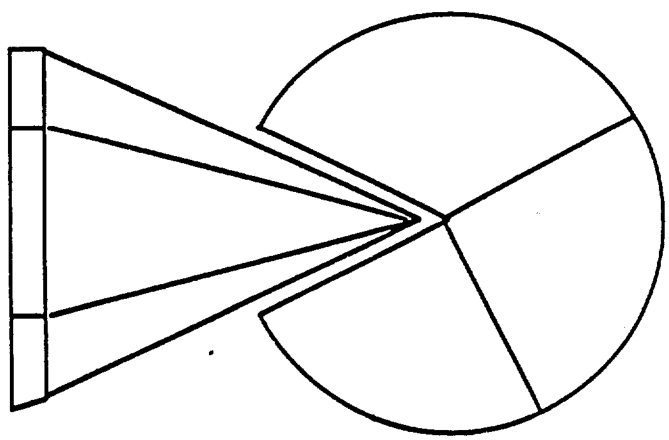
a. As available, use standard military symbology, conventions, and procedures to construct flow charts, especially when constructing organizational charts.



a. Tonal coding. Emphasize an important segment by using a special tonal or color code. Here black, the most dominate tonal code, is used to draw attention to the segment. The remaining segments are not coded to further deemphasize their importance.



b. Displacement. Emphasize an important segment by displacing it. All segments may be coded to differentiate them.



c. Displacement of a subdivded segment. To provide added emphasis and detail, break the segment into subcomponents outside the pie.

Figure 35. Pie Chart Construction.

Note. From Using charts and graphs (p. 15). By J. V. White, 1984. New York: R. R. Bowker Company. Adapted by permission.

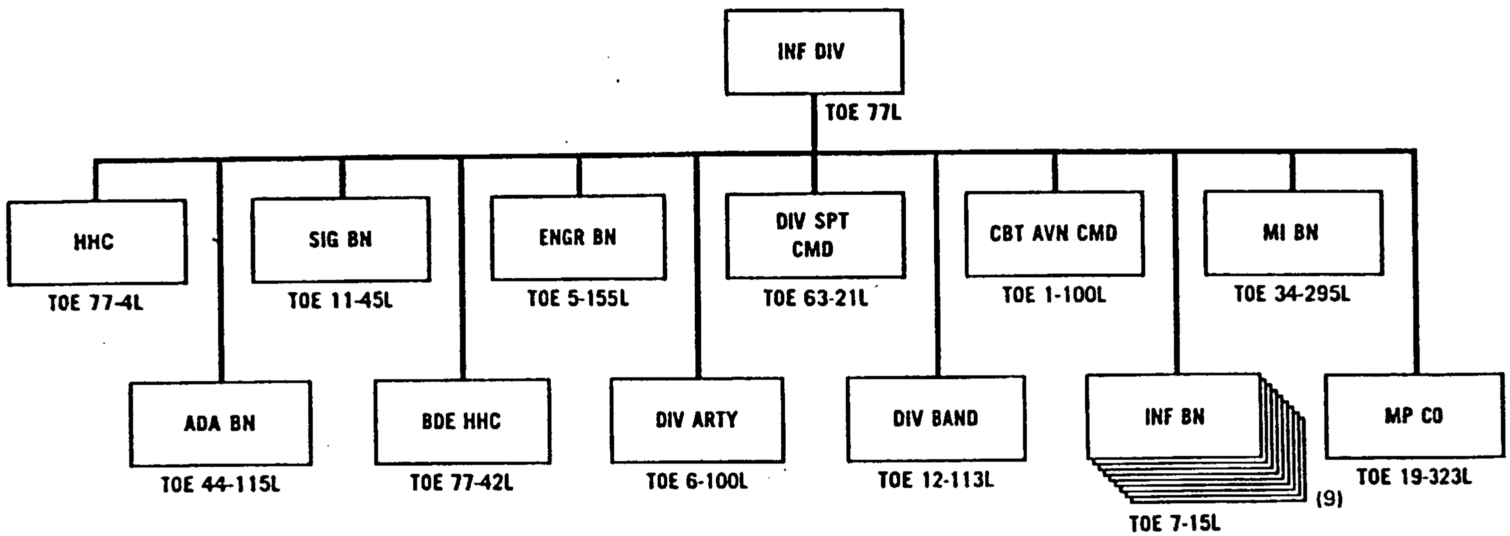


Figure 36. Organizational chart: Light Infantry Divsion.

b. The flow chart title and each element should be labeled clearly.

See 2.5.5.3. Process chart.

2.5.5.3. Process chart. This graphic form provides a systematic description of a process or work cycle involving activities of humans, agents or objects and provides other information for analysis such as time required, distance moved, costs, etc. A process chart, which is conveyed in a tabular or schematic format, uses symbols to portray the sequence of all relevant actions or events occuring during a process.
Process charts have a variety of uses, but they are used most often for analysis, for job instruction and training, and to show ways of improvement.

American Society of Mechanical Engineers (1980).

2.5.5.4. Graphic aids.

a. Consider using flow charts that depict relationships among system components, processes, or data as graphic aids to help users learn about a computer system and its operational procedures. To construct these flow charts use the principles and practices for constructing flow charts endorsed by the American National Standards Institute (ANSI), as applicable (e.g., ANSI X3.5-1970).

American National Standard Institute (1970).

b. Consider providing computer generated displays of process charts to assist users in managing or analyzing command and control activities.

2.5.6. Map displays. Map displays show geographic relations among operations, activities, resources, objects, or other subjects of interest. Situation maps, topographic maps, and statistical maps are types of map displays.

2.5.6.1. Construction.

2.5.6.1.1. Map symbols.

2.5.6.1.1.1. Military symbols. Use standard-doctrinal symbology on battlefield situation maps, whenever available.

FM 101-5-1 (1985); Parrish et al. (1983).

2.5.6.1.1.2. Exact locations. Place symbols on the map at exact locations. When it is not possible to place symbols at exact locations, place the symbol near the location and use an arrow to indicate its exact location. However, always consider alternative ways of presenting the map display to reduce its density and circumvent the need for using arrows to connect symbols and locations since the arrows add clutter.

Parrish et al. (1983).

2.5.6.1.1.3. Overlap. Map symbols should not overlap, unless the symbols can be clearly and unambiguously identified.

a. When graphics data are in the process of being changed or automatically updated by the system (i.e., when data are moving on the display), symbols temporarily may overlap and obscure other symbols or permanent background features.

b. Prioritize graphic elements or data categories, identifying which elements may be obscured by others. Restore the obscured or overlaid elements when the update is completed; and ensure that no elements are erased from the display during the process of obscuration and restoration.

See 2.5.6.2.7. Dynamic capabilities; 2.6. Dynamic displays.
Parrish et al. (1983); Smith and Mosier (1986).

2.5.6.1.1.4. Labels. Map symbols and features require identifying information so they can be clearly understood. Provide labels of symbols and other map features directly on the map display (e.g., the mandatory field designators for units, command posts and installations, or equipment).

a. If the density of the display precludes the use of contiguous labels, consider displaying labels and additional information about the display items (e.g., optional field designators of unit symbology such as evaluation rating, combat effectiveness, higher formation, direction of movement) in a legend or key or supplementary display. Also, consider allowing the user to obtain the information by selecting or pointing at the item of interest.

b. The labels should be positioned consistently in relation to their referent symbol or feature. Unnecessary variability in the arrangement and organization of the display adds to the time it takes the user to perceive and then process the information on the display. For example, graphic and alphanumeric identifiers for units, installations, and equipment should be arranged in the mandatory, conditional and optional fields as specified in FM 101-5-1, Operational terms and symbols.

FM 101-5-1 (1985).

2.5.6.1.2. Background features. To assist users in their design of effective topographic displays, familiarize users with the optimum combinations of background features (e.g. topography, vegetation, contour lines, and grid lines).

Swezey and Davis (1983).

2.5.6.1.3. Contour lines.

a. Avoid the use of contour lines representing graduations finer than 20 meters because they produce visual clutter and potentially can cause eye fatigue.

b. Do not rely solely on contour lines to separate the areas of a map display. So that unambiguous figure ground relationships will emerge, consider differentiating the display surface by using texture, shading, color or shape of objects.

See 2.5.6.1.4. Framed rectangle graphs.
Swezey and Davis (1983); McCleary (1981).

2.5.6.1.4. Framed rectangle graphs. As an alternative to shading, consider using framed rectangle graphs to encode data on statistical maps. Shading requires judgments of density, and framed rectangle graphs require judgments of position along nonaligned, identical scales. The latter judgments are performed more accurately. In addition shading patterns can create adverse visual effects.

See 2.4. Coding.
See Figures 37 and 38.
Cleveland (1985).

2.5.6.2. Graphic aids.

2.5.6.2.1. Presentation techniques. To draw attention to specific areas of interest or importance on a map display and to facilitate user integration of the information, consider using two-dimensional and three-dimensional presentation techniques.

2.5.6.2.1.1. Two-dimensional.

a. Consider dismembering the areas of the map by separating them. To highlight the areas of interest, use color coding, shading, symbology or segregate the areas of interest from the rest of the areas on the map.

b. Display the areas of interest and leave the rest of the map blank.

See Figure 39.

2.5.6.2.1.2. Three-dimensional.

a. Consider displaying the areas of interest as blocks rising above or sinking below the surface of the map.

b. Consider displaying the map's entire surface area at a lower angle to show its levels. Highlight the areas of interest by depicting them as peaks (above surface) or valleys (below surface).

See Figure 40.
White (1984).

2.5.6.2.2. Coding and sequencing techniques.

Consider using a coding or sequencing technique to segregate and highlight symbolic information on high density map displays, particularly for displays where the pictographs and other symbology may overlap temporarily and are repeatedly updated (e.g. battlefield situation map displays).

2.5.6.2.2.1. Coding techniques. To make selected pictographs and other symbology on a complex map display more distinguishable, consider using double cue coding and color coding techniques.

a. Double cue coding. This coding technique is advantageous because it does not add new symbology to the display, but rather augments a measurable dimension of existing symbology (size, length or width). For example, to denote an update or change in status of a military unit on a battlefield situation map display, the specific unit pictograph can be emphasized by blinking the symbol on and off.

b. Color coding. Color is a dominant coding dimension, and it may obviate the perception of features coded in other visual dimensions. Therefore, in complex map displays, consider color coding those symbols that provide information that is of primary or first level

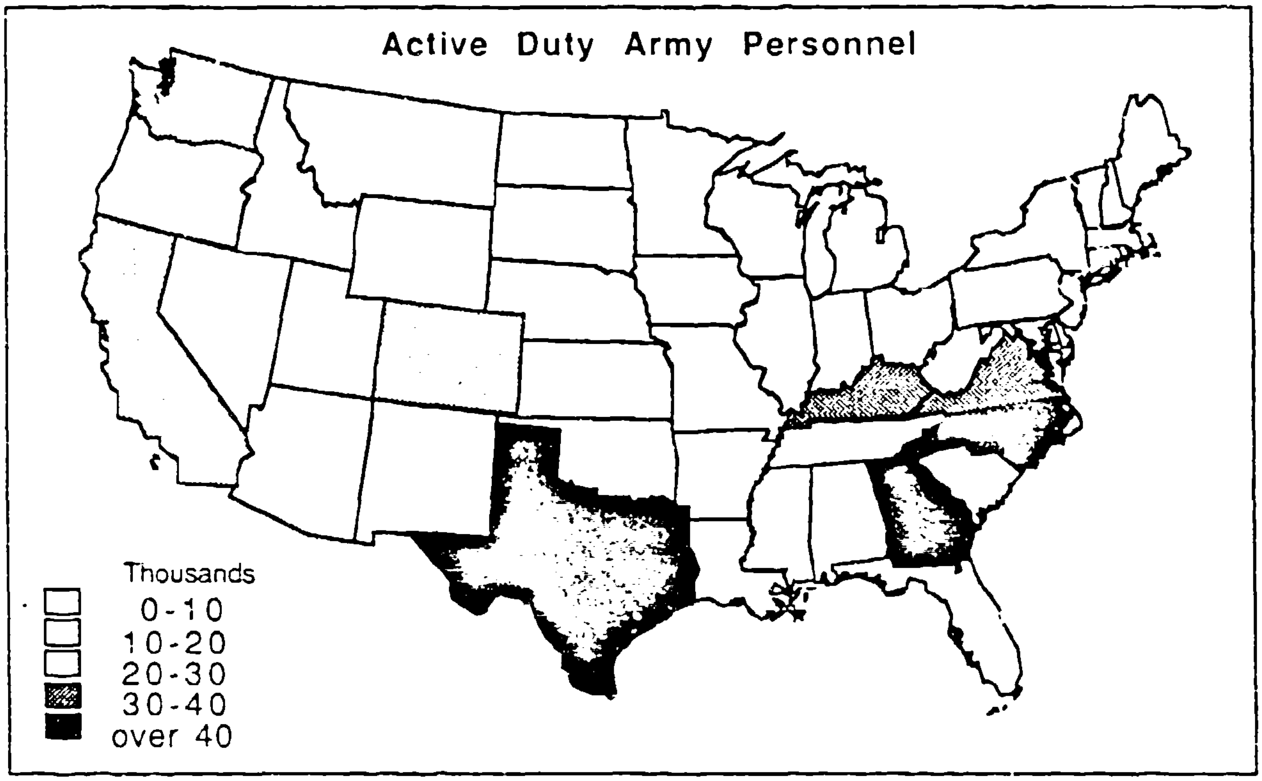


Figure 37. Shaded statistical map.

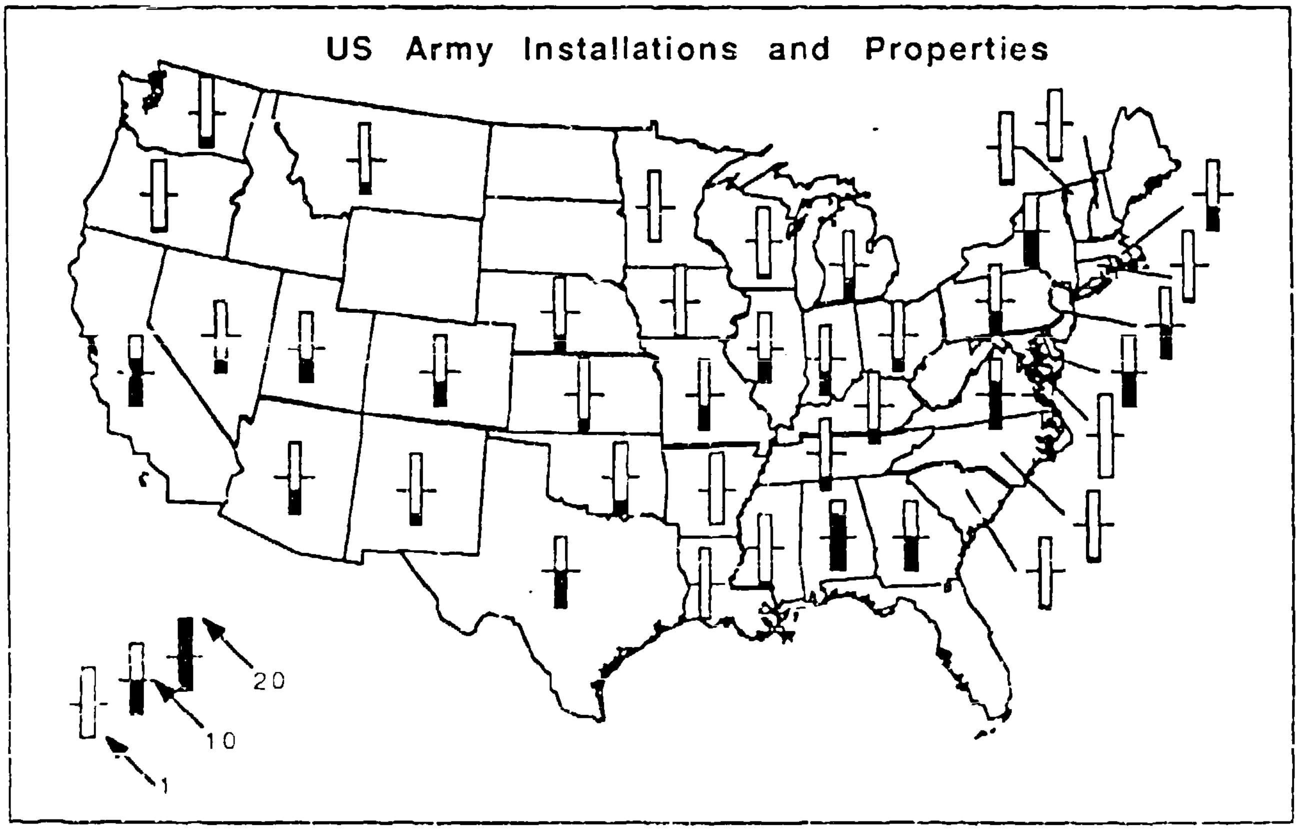
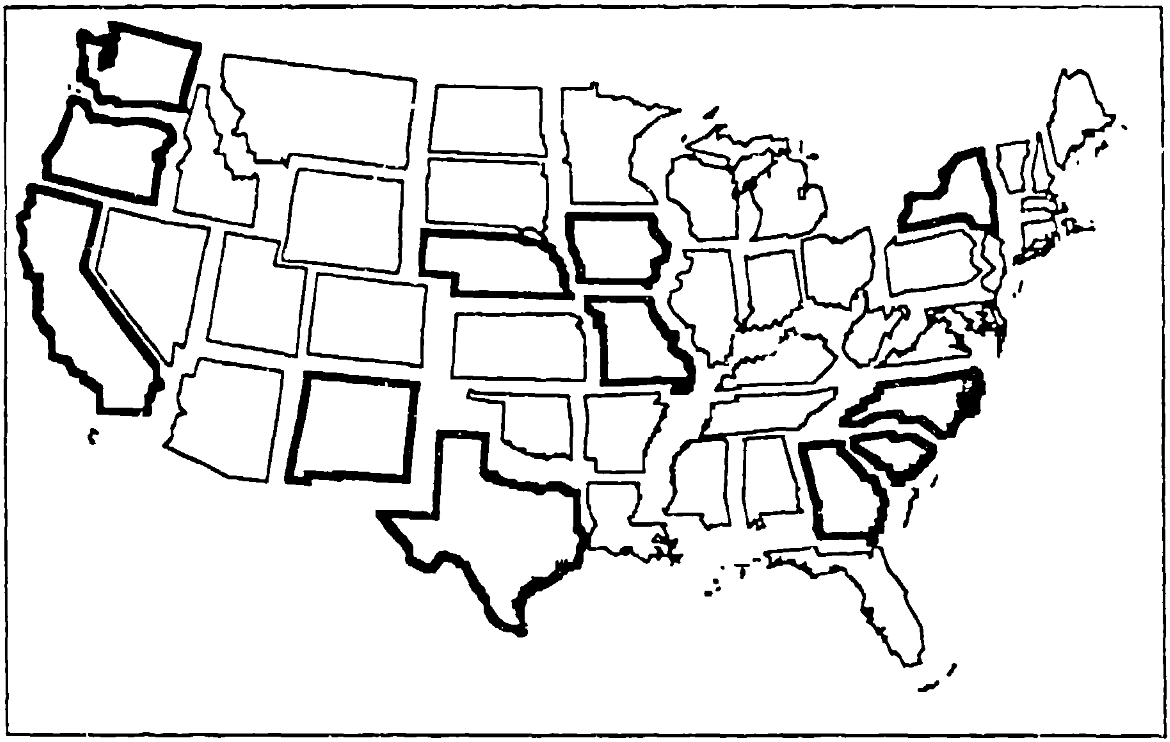
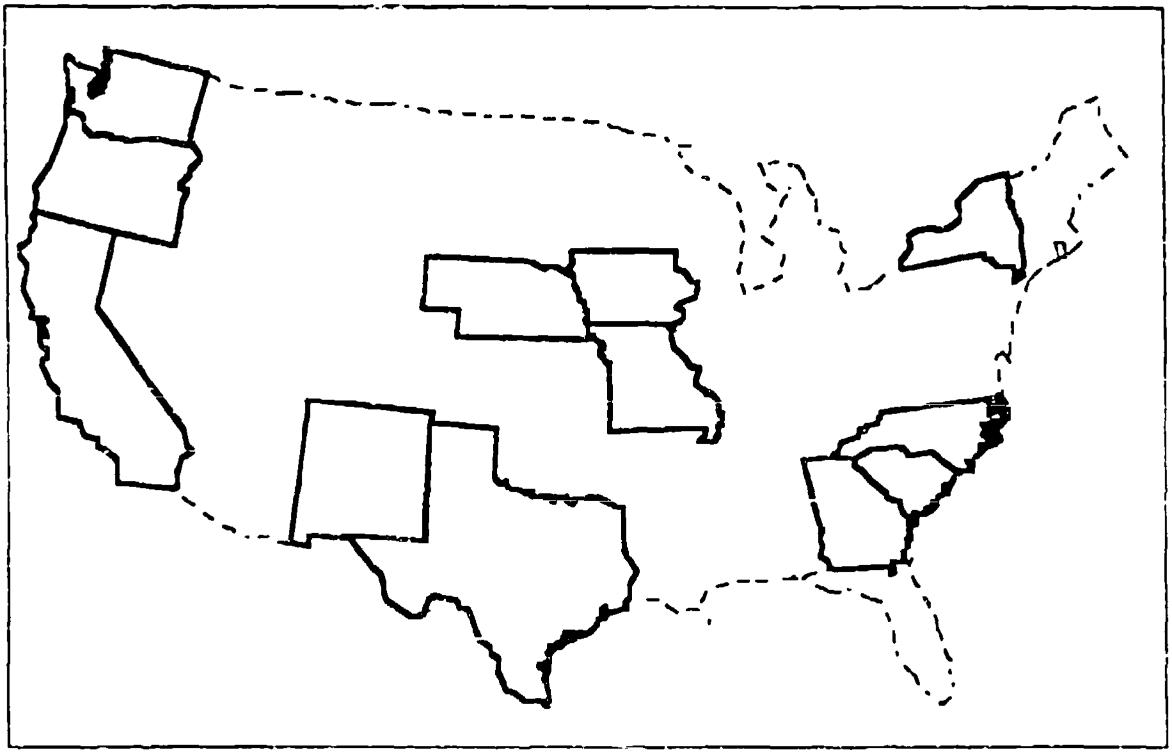


Figure 38. Framed rectangle graph.



a. To focus user attention to geographic areas of interest separate the areas of the map display and then use a coding technique to highlight the areas of interest.



a. To emphasize specific geographic areas, draw the areas of interest and leave the rest of the map blank.

Figure 39. Two dimensional presentation techniques for map displays.

Note. From Using charts and graphs (p. 117) by J. V. White, 1984. New York: R. R. Bowker Company. Copyright by Jan V. White. Adapted by permission.

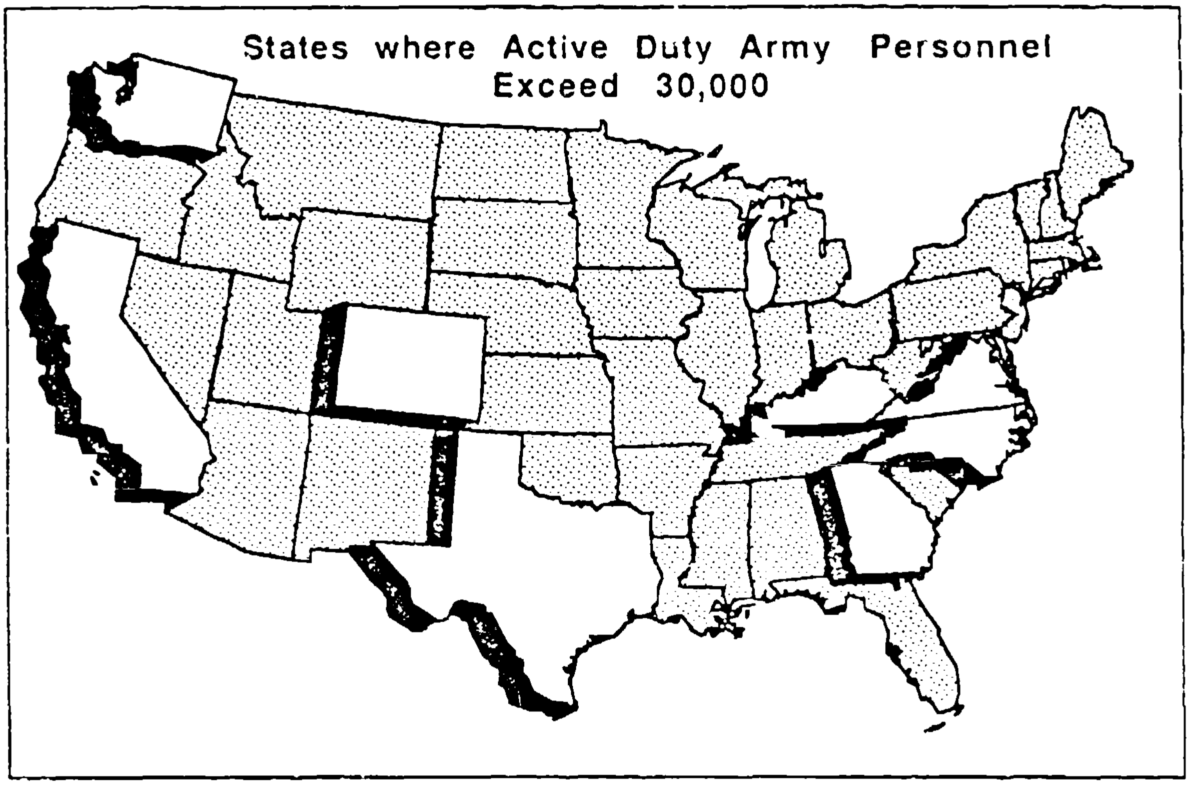


Figure 40. Three dimensional presentation techniques for map displays.

interest to the user. When primary information requirements are not known or if the display will be used for multiple tasks, consider placing the color coding under user control (such as by means of function keys).

Knapp, Moses and Gellman (1982).

2.5.6.2.2.2. Sequencing techniques. Provide sequencing techniques as standard functions in the interface. Sequencing techniques can reduce the number of symbols on map displays at any one time by displaying segments of the entire display over time. Also, sequencing techniques permit the user to view areas of interest, when the map exceeds the capacity of a single display frame.

a. Consider facilities that will permit the user to display segments sequentially in discrete static views, or facilities that will permit the user to scan the display segments.

b. For battlefield situation map displays, consider providing facilities to display topographic information sequentially with an overlap between views to facilitate user integration of the information.

See 2.5.6.2.3. Panning technique.
Knapp, Moses, and Gellman (1982).

2.5.6.2.3. Panning technique. Consider providing a panning capability to permit the user to examine an area of interest in greater detail when the display area exceeds the capability of a single frame in terms of extent and level of detail. The panning capability will permit users to move continuously over a map display in any direction without encountering any internal boundaries imposed by the predefined display framing.

DOD-HDBK-761A (1987); Smith and Mosier (1986).

2.5.6.2.4. Zooming technique. Consider providing a zooming capability, that will permit users to expand the map display for viewing at various levels of detail. A zooming capability will allow users to control and personalize map displays, so that the displays can more effectively satisfy users' individual information requirements.

a. Consider designing the map displays with hierarchical levels of portrayed detail and labeling so that the user can zoom in to examine an area in greater detail and zoom out for an aggregated display. However, when graphic data are layered hierarchically at different levels of detail, complex data files and data management techniques may be required.

b. Also, consider implementing zooming as a continuous function, by which a display can be expanded to any degree.

Smith and Mosier (1986).

2.5.6.2.5. Inset. To assist the user in maintaining his orientation when using a sequencing, zooming, panning or other technique to examine a segment of the entire display, provide some type of graphic indicator of the user's current position in the overall map display. Consider using an inset that gives a dynamic scale-model representation of the displayed area mapped onto a block representing the entire display surface.

Knapp, Moses and Gellman (1982); Nickerson (1986); Smith and Mosier (1986).

2.5.6.2.6. Normal display coverage. If panning, zooming, or other techniques are available to the user that cause a change in the normal display coverage, provide an easy means for the user to return to the normal display coverage (e.g.,the use of function keys labeled "Return" or "Reset"). Normal coverage may be user defined or predefined by default system parameters.

Smith and Mosier (1986).

2.5.6.2.7. Dynamic capabilities. Consider providing dynamic display capabilities that will permit users to simulate activities on a situation display (e.g. projected movement of the forward edge of the battle area [FEBA]). Such a capability is particularly important in command and control applications to support the war gaming and decision making process.

See 2.6. Dynamic displays.

2.5.6.2.8. Analytic aids.

2.5.6.2.8.1. Distance judgments. When users must judge distances accurately on a map, consider providing computer aids for that purpose. For example, consider permitting users to select any two points, and have the system provide the separation distance.

Smith and Mosier (1986).

2.5.6.2.8.2. Topographic analysis. Consider providing computer aids to help users perform analysis of topographic displays (e.g., aids to support terrain analysis, calculate slopes, and calculate sight angles to determine radar coverage).

Smith and Mosier (1986).

2.5.7. Three or more dimensional forms. Generally, the use of three or more dimensional presentation formats should be restricted to users who are familiar with advanced statistical presentation formats, techniques and methodologies.

2.5.7.1. Pictographic scales. Consider using pictographic or character scales to present multidimensional data (e.g. Anderson's glyphs, Cernoff's faces, sunflowers, weathervane, stars or polygons, and Kleiner-Haritgan trees described in detail in Tukey and Tukey, 1981).

a. Select and design pictographic scales so that the scales are separable. The scales should allow the user to easily shift attention from one coded aspect to another.

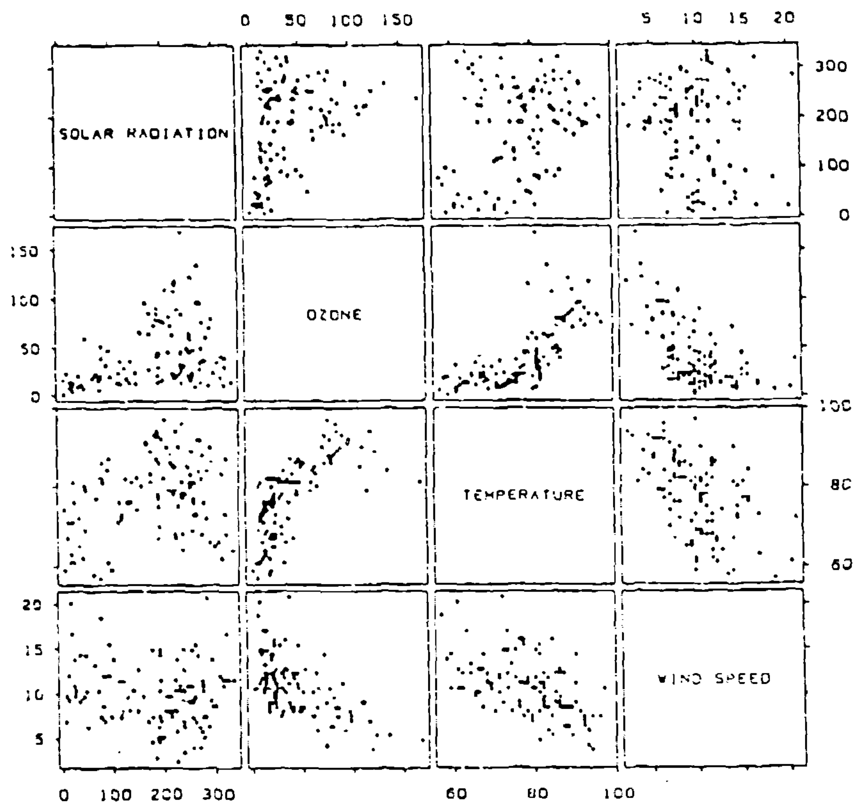
b. Select and design pictographic scales so that the individual values coded can be intergrated to form an overall impression of trends in the data.

Tukey and Tukey (1981).

2.5.7.2. Multiple displays. Consider using a series of small multiple displays to present multidimensional data (e.g., multiple bivariate displays to present multidimensional data of four variables).

See Figure 41.
Cleveland (1985); Tufte (1983).

2.6. Dynamic displays.



The multiple scatterplots represent data on solar radiation, ozone, temperature, and wind speed from 111 days. To read the chart use the labels and scales to the right or left and top or bottom of all charts, e.g. the chart in the upper right hand corner represents a scatterplot of solar radiation and wind speed measurements.

Figure 41. Multiple bivariate displays.

Note. From The elements of graphing data (p. 211), by W. S. Cleveland, 1985. Pacific Grove, CA: Wadsworth Advanced Books. Copyright © 1985 Bell Telephone Laboratories, Inc., Reprinted by permission of Wadsworth Advanced Books, Pacific Grove, CA.

2.6.1. Changing values. Update alphanumeric values that a user must reliably read no more than once per second. When the display is to be considered as real time, update alphanumeric values that a viewer uses to identify rate of change or to read gross values no faster than five times per second, and no slower than two times per second.

MIL-STD-1472 5.15.3.4.1.

2.6.2. Update rate. The rate of update on a dynamic display should be controllable by the user and shall be determined by the user's informational requirements.

MIL-STD-1472 5.15.3.4.2.

2.6.3. Display freeze. Provide a display freeze mode to allow the user to scrutinize closely any selected frame that is updated or advanced automatically by the system. For frozen display frames, provide an option to allow the user to resume the display at the point of stoppage or at the current real-time point.

2.6.3.1. Freeze feedback. Provide an appropriate label or graphic indicator to remind the operator when the display is in the freeze mode.

MIL-STD-1472 5.15.3.4.3; MIL-STD-1472 5.15.3.4.4.

Section 3. Interactive Dialogue

The guidelines in this section concern user-computer graphic communication. The guidelines are partitioned into two broad categories: Interaction tasks and Iconic dialogue. The section, Interaction tasks, describes the basic task components of the interactive dialogue and the capabilities of interaction techniques that are required to support the user's efficient performance of these tasks. Iconic dialogue provides guidelines concerning the design and use of icons, which are graphic dialogue elements.

3.1. Interaction tasks.

Consider including interaction techniques in the interface that will permit the user to perform the following user-oriented interaction tasks. These interaction tasks, which are independent of application and hardware, are postulated to be the elementary task components or building blocks of more complex interaction tasks and complete interaction dialogues. The user performs these tasks to enter or operate upon graphic elements, to construct a graphics display and to manipulate and edit graphics data or other display elements.

See 3.1.1.3.1. Display selected attributes.
Foley, Wallace and Chan (1980, 1984).

3.1.1. Selection.

Include interaction techniques that will permit the user to make a selection from a set of alternatives (e.g., selections from a collection of displayed elements such as data points on a graphics display, unit symbology on a battlefield situation map display or selections from a set of commands or menu options).

3.1.1.1. System data base. Permit users to select data from the systems' data base for portrayal in a graphic format.

Parrish et al. (1983).

3.1.1.2. Standard formats. Permit users to select standard graphic formats for the presentation of graphics data (e.g., bar graphs, column graphs, arithmetic line graphs, etc.).

See 2.5. Graphic Forms.
Parrish et al. (1983).

3.1.1.3. Attributes for graphic elements.

The capabilities provided should permit the user to specify the attributes for graphic elements (e.g., cross-hatching patterns, plotting symbols, line type, color, and text font and size) and to change attribute selections (e.g., to edit a graphics display). Ideally, the attributes should be selected from displayed samples illustrating the set of available options.

a. Generally, the current selection of attributes should remain in effect until a new selection is made; however, in selected cases, it may be more appropriate to permit the selected attributes to reverse back to default values when the interaction sequence is completed.

b. Permit the user to change attribute selections. Users should be able to change display attributes by the same means used initially to select the attributes (e.g., if a cross-hatching pattern was selected originally from a list of menu options, the menu options should be used to change the pattern). Graphic data entry and graphic data editing are temporally-proximal actions; and therefore, entry and editing actions should be executed using consistent actions.

Smith and Mosier (1986).

3.1.1.3.1. Display selected attributes.

In applications where display cues do not convey adequately attribute information, display the selected attributes so that the user knows which attributes are currently operative.

a. A display of the current selected attributes is important because users may forget what options have been chosen and a reminder may prevent user errors.

b. Exemplary techniques for displaying selected attributes include: highlighting selected menu options; displaying attributes in an "inset" or "reference" window; and changing cursor shape, size or color depending upon current attribute selections. Also, consider permitting users to request an auxiliary display of attribute information, particularly when there is not sufficient screen space to display attribute information or when the attributes derive from models whose characteristics are too complex for a simple display representation.

See 3.1.1.4. Highlighting; 2.4.1. Selective Highlighting.
Smith and Mosier (1986).

3.1.1.3.2. Color.

a. When color can be selected as an attribute of graphic elements, allow users to specify colors directly rather than requiring them to name the colors (e.g., by "pointing" or "clicking" when making selections from a list of options in a menu). In systems where there are only a few colors (such as the basic colors of the spectrum) names of colors may be used reliably. However, where many colors are available, users with normal color vision can select from displayed samples more reliably than from a list of color names. To aid users with color-vision deficiencies, consider labeling the displayed colors with their color names.

b. Consider providing capabilities for users to mix colors by cursor positioning either in a displayed palette or directly in a graphic image. By mixing colors users can control the saturation, brightness and opacity or transparency, as well as hues of graphic elements. By mixing colors one can create more effective color displays.

See 2.4.6. Color coding.
Foley, Wallace and Chan (1980, 1984); Smith and Mosier (1986).

3.1.1.3.3. Symbols. Provide a standard set of symbols from which a user can make selections for incorporation in the graphics display. For example, to construct a map overlay or to update a computer generated situation map, a user could select doctrinal military symbology from lists of options in sequentially displayed single-level menus.

Parrish et al. (1983).

3.1.1.4. Highlighting.

To provide visual feedback to the user, highlight a graphic element when it is selected on the graphics display (e.g., a unit symbol). Exemplary highlighting techniques include the placing of a dotted border around the selected element and displaying the element in reverse video to distinguish it from other graphic objects on the display. As possible, the highlighting used should help the user anticipate the consequences of any proposed actions involving that selection; for example, elements selected for deletion can be highlighted consistently in reverse video.

See 2.4.1 Selective hightlighting; 3.1.1.5. Deletion.
Foley, Wallace and Chan (1980, 1984); Smith and Mosier (1986).

3.1.1.5. Deletion.

a. Permit the user to select items for deletion or erasure; however, deletion should be implemented as a reversible action. Consider providing a general "UNDO" capability to reverse deletions. Also to support users in complex graphic tasks, consider providing a more comprehensive capability, where the user can save deleted graphic elements in a computer scrap basket or user scratch pad for retrieval any time during the interaction sequence.

b. Consider hightlighting (e.g. reverse video) the items that have been selected for deletion to give the user feedback concerning his choice, which then can be checked for accuracy before executed.

Smith and Mosier (1986).

3.1.2. Positioning.

Include techniques in the interface that will permit the user to position and reposition a graphic element on the display (e.g., a line segment, a unit symbol, or other display entity using "dragging", "cut-and-paste", keyboard entry of coordinates, or other means). A capability for moving graphic elements will support initial data entry and editing. Also, repositioning graphic elements generally will be easier and more efficient than deleting and then reconstructing the graphic element in its desired location.

3.1.2.1. Feedback. As possible to do so, select techniques that will provide both continuous and discrete feedback for positioning tasks.

3.1.2.1.1. Continuous feedback. When feedback is continuous, visual feedback of the object's location is provided as the object moves through a succession of trial positions until the desired position is reached. Generally, continous feedback is appropriate when the user knows where on the screen the position of interest is but does not know its exact numeric coordinates (e.g., when a user repositions units to update a battlefield situation map using geographical location rather than unit coordinates).

a. It is probably not necessary to depict the object in complete detail when it is being repositioned. It might suffice to show it in simplified outline until its new position has been confirmed by the user or perhaps until it remains in one positon for a fixed interval of time, at which point its details could be filled in again.

3.1.2.1.2. Discrete feedback. When feedback is discrete, visual feedback of the object's location is not echoed on the display while the object is being positioned. Generally, discrete feedback is appropriate when the user knows the numeric coordinates but not the desired positions (e.g. when a user repositions units to update a battlefield situation map using unit coordinates).

3.1.2.2. Zooming. To make the positioning task easier when exact positioning of a graphic element is required or to support user information extraction on a high density display, provide a zooming capability so that the user can expand any selected display area.

Foley, Wallace and Chan (1984); Smith and Mosier (1986).

3.1.2.3. Grid. Consider superimposing a grid on the display or placing a coordinate axes along the edges of the display to help the user align positions or objects or to convert a position on the screen into numeric coordinates for keyboard entry. To prevent interference with other information, present the grid or axes at low intensity.

Foley, Wallace and Chan (1984)

3.1.3. Orienting.

Include interaction techniques that will permit the user to orient any two-dimensional or three-dimensional entity. Exemplary tasks are the rotating of a two-dimensional symbol so that it points in another direction and the changing of the viewing angle of a three-dimensional symbol.

See 3.1.2.1.1. Continuous feedback; 3.1.2.1.2. Discrete feedback; 3.2.5.1. Three-dimensional symbols.
Foley, Wallace and Chan (1984).

3.1.4. Pathing.

Include interaction techniques in the interface that will permit the user to generate a path, which is a series of positions or orientations created over time. Examples of tasks where a user may generate a path of positions or orientations are: (l) drawing curves or lines to construct an arithmetic line graph; (2) creating an overlay or placing a desired route on a map; and (3) simulating unit movement on a battlefield situation map by both repositioning and reorienting unit symbols.

Foley, Wallace and Chan (1980, 1984).

3.1.5. Quantifying.

Include techniques that will allow the user to execute quantifying tasks, those tasks where a user specifies a value or number from a range of values to quantify an entity. Quantifying tasks include the specification of: (1) the values of scale divisions for the veritical and horizontal scales of a graph; (2) the height of a column or width of a bar; and (3) the size of icons and other graphical symbology.

Foley, Wallace and Chan (1980, 1984).

3.1.6. Text entry.

Include techniques in the interface that will permit the user to input text strings on graphic displays. Typical text entry tasks associated with graphic displays include annotating and labeling situation maps and map overlays, placing titles, subtitles, and scale labels on graphs, and entering the text in keys or legends.

a. Users should be able to use the alphanumeric features of the system to enter text on graphic displays (e.g., direct entry from the keyboard).

Foley, Wallace and Chan (1980, 1984); Parrish et al. (1983).

3.1.7. Multiple interactive techniques.

To accomodate different user characteristics, provide several interaction techniques for the same task, as possible to do so.

a. For example, menu selection and function keys are interaction techniques that can be used for selection tasks. However, novice users prefer menu selection; and experienced, frequent users prefer function keys, because they have memorized them.

b. If multiple techniques are provided, incorporate a transition mechanism in the interface that will move users from the use of one technique to another.

Foley, Wallace and Chan (1984).

3.1.8. Presentation guides user action.

To guide user actions, design the context presented to the user at each interaction point so that it suggests the actions which the user can take upon that context. The context is what the user sees as he interacts with displayed data. For example, when a user edits a displayed graphic element by selecting options from a menu, highlight only those options that are appropriate user actions for the present task being performed in the interaction sequence.

Bennett (1976).

3.2. Iconic dialogue.

Icons are pictographic symbols used as part of the dialogue to represent computer entities and data. These symbols can indicate attributes, associations and states of computer entities and data. They include two-dimensional and three-dimensional symbols.

Gittens (1986).

3.2.1. Advantages. The use of icons in the interface has the advantages listed below.

3.2.1.1. Screen space. The amount of space for displaying information on a computer screen is a finite quantity and must be used judiciously. Because icons can represent a lot of information in a small amount of space, they can be used to conserve screen space.

Hemenway (1981); Sumikawa (1985).

3.2.1.2. Interactive dialogue. The dialogue between the computer and the user is potentially faster with symbols than words.

3.2.1.2.1. Distinctive targets. As display targets, icons are more visually distinct from one another than are words and can be spotted easier than a written word.

Hemenway (1981); Sumikawa (1985).

3.2.1.2.2. Recognition and processing. The majority of users may recognize and process graphical images faster than words.

a. When icons are miniature pictures of the objects or operations they represent, mental processing is less dependent on formal learning as is required in the processing of words that are very dependent on a specific language and culture.

Huggins and Entwisle (1974).

b. Icons are easily learned, retained, and recalled as single units of information due to the powerful processing ability of human image memory and processing capabilities.

Glinert, Ephraim, and Tanimoto (1984).

3.2.1.2.3. Iconic menu selection. Iconic menu selection is potentially faster than words or phrases in menu selection.

a. Icons facilitate faster user response because tactile movements are acquired easily and with the continued use of iconic menus the user response rate becomes more automatic.

Marcus (1984).

b. Icons can decrease cognitive load in menu selection if the icons evoke immediate association with their equivalent text strings.

Foley, Wallace and Chan (1984).

c. Icons encourage users to explore the visual relationship and organization of objects more than is the case with commands. Because organization facilitates retention, iconic menus may improve the overall learning and recall of the operational procedures of the interface.

Gittens (1986).

3.2.1.3. Universality. Icons can be used to design a computer interface that is useable by persons of different cultural groups and linguisitic backgrounds. By replacing written words in the computer interface with culture-free, universal symbols computers can be used effectively by diverse user populations. (e.g., U.S. officers and allied officers).

Marcus, 1984; Sumikawa, 1985.

3.2.2. Disadvantages. The use of icons in the interface have the disadvantages listed below.

3.2.2.1. Testing. Design of efficacious icons may require extensive testing.

a. The information conveyed by any symbol depends on a viewer's experience and knowledge, which is determined largely by cultural factors. Careful testing may be required to develop a statisfactory set of icons to achieve legibility and consistency in interpretation, especially when users vary in cultural and linguistic backgrounds.

b. Generally, all symbols should be tested for the meanings they evoke before using them to display information to any group of users.

See 3.2.3.1.2. Meaningfulness of form.
Bersch, Moses & Maisano (1978); Smith and Mosier (1986).

3.2.2.2. Transition to other media. Because iconic menus may not support the transition to the use of other media, iconic menus may be more appropriate for intermittent rather than continuing use. For example, it is believed that iconic menus do not support the sequential concatenation of coded menu selection that can ease the transition to command entry as novice users become more experienced. To support the transition from the use of icons to other media, special facilities may be required in the interface.

See 3.2.5.1. Aiding techniques: Transition.
Hemenway (1981); Smith and Mosier (1986).

3.2.3. Structure and design.

3.2.3.1. Gestalt Principles. Consider these Gestalt principles when designing icons, which generally provide the theoretical foundation for the specific iconic guidelines detailed.

3.2.3.1.1. Pragnanz. As per the Gestalt law of pragnanz, people prefer the simplest or most efficient interpretation of a symbolic representation.

a. Defined in terms of the amount of information content, efficiency can be measured as the count of the number of structural symbols contained in a symbolic representation, excluding metric quantities that determine the scale but have no bearing on the shape (e.g., lines, angles, squares, cubes, repetitions, and reversals).

Chase (1986); Leeuvenberg (1968, 1971); van Tuijl (1980).

3.2.3.1.2. Meaningfulness of form. A form tends to be meaningful and to have objectivity. The more meaningful the form, the stronger it is, the more easily it is perceived, and the longer it tends to persist.

See 3.2.3.2. Concrete concepts.
Pomerantz and Kubovy (1986).

3.2.3.1.3. Priniciples of grouping.

3.2.3.1.3.1. Proximity. Elements that are in close proximity of one another will tend to group.

3.2.3.1.3.2. Similarity. Elements of similar shape or form will tend to be perceived as a group.

3.2.3.1.3.3. Closure. When elements are arranged so they define a closed region, they will group together to form perceptually unified shapes.

3.2.3.1.3.4. Good continuation. Figures will organize to make the fewest changes or interruptions in straight or smoothly curving lines.

3.2.3.1.3.5. Symmetry. Elements will group to maximize the symmetry of their resulting organization.

3.2.3.1.3.6. Common fate. Elements in a visual field undergoing simultaneous, correlated changes will tend to be grouped together.

See Figure 42.
McCleary (1981); Pommerantz and Kubovy (1986).

3.2.3.1.4. Rules of figure ground organization. The figure is the perceived entity that has shape which stands out from the background. The ground is perceived to continue behind the figure. Consider these basic rules of figure ground organization when designing icons.

3.2.3.1.4.1. Area. The size of a figure relative to its ground affects perception. Smaller closed regions of the visual field are more likely to be seen as figure than are larger ones. Consider a figure:ground ratio of at least 1: 1.5.

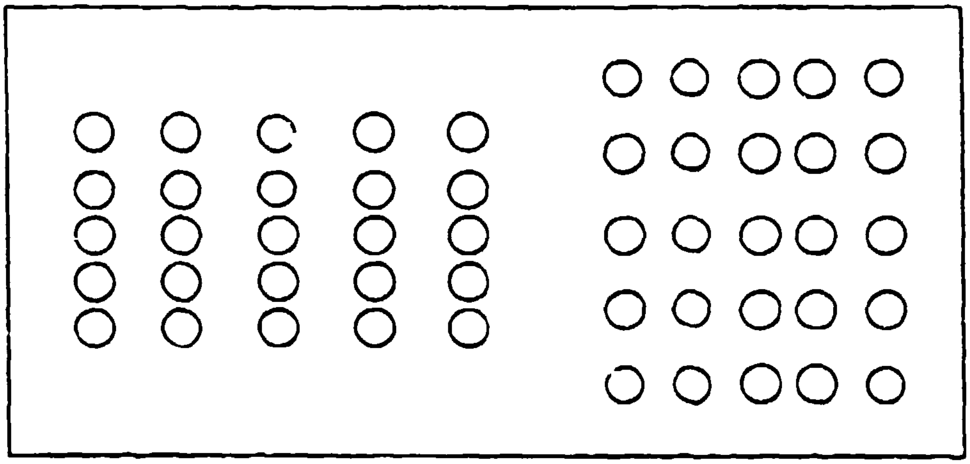
3.2.3.1.4.2. Convexity. When shape is the single dimension varied, convex shapes will be seen as figures and concave shapes will be seen as grounds (holes).

3.2.3.1.4.3. Contour. A given contour (line) will be seen as belonging to only one of the two regions it delineates at any one time. This rule is sometimes called the "one-sided function of contour."

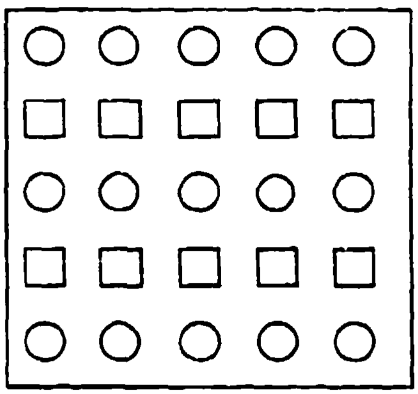
3.2.3.1.4.4. Position. Centrally located objects tend to be seen as figures. If a surface is divided horizontally into two parts, the lower portion will be seen generally as the figure.

3.2.3.1.4.5. Contrast. The less the difference between the areas of a display, the weaker the figure-ground relationships. Constrast strengthens figure ground relationships. When brightness is used as the single coding strategy to obtain contrast, darker areas will emerge as figures; and similarly when texture coding is used, the coarser textures will tend to be seen as figures.

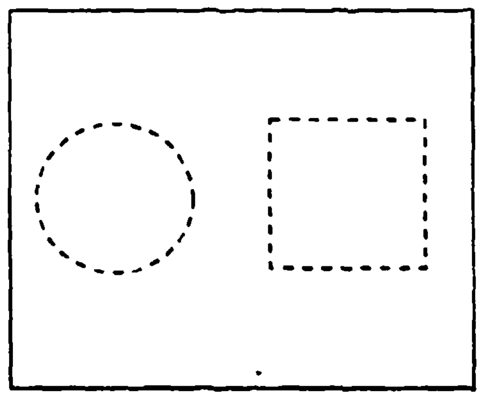
See 2.4. Coding.
McCleary (1981); Rock (1986).



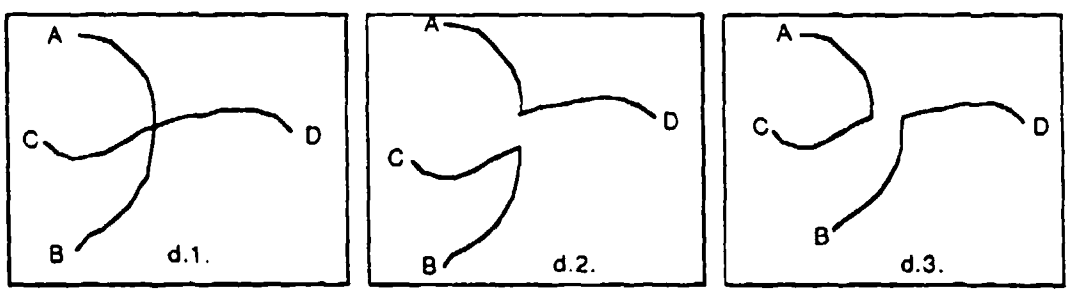
a. Proximity: Objects tend to group in columns if the vertical spacing is less than the horizontal. If horizontal spacing is less they group in rows.



b. Similarity: Items tend to group into rows of identical shapes.



c. Closure: When elements are arranged so they define a closed region, they will group to form unified shapes.



d. Good continuation: Elements will group so as to minimize abrupt changes in a contour's direction. A to B forms one line and C to D another (in d.1.) The alternate groupings (in d.2. and d.3.) are not usually perceived.

Figure 42. Illustration of four Gestalt principles of grouping.
(Adapted from Pomerantz and Kubovy, 1986.)

3.2.3.2. Concrete concepts. Icons are more effective for concrete concepts than for abstract concepts. Icons for abstract concepts must be developed and tested extensively testing for meaning, legibility and consistency in interpretation.

a. Concrete concepts generally have existing symbolic representations that are within the user's experience. When these representations are used in the computer interface, the icons are not new and are inherently more meaningful. The propositional theory of human memory postulates that information is stored as an abstract propositional network according to its meaning. In this respect, the greater meaningfulness inherent in icons of concrete concepts potentially may enhance information processing and facilitate recall of the information conveyed by the icon.

See 3.2.3.1.2. Meaningfulness of forms; 3.2.3.3. Simplicity.
DeSanctis (1984); Anderson (1980)

3.2.3.3. Simplicity. Avoid the use of over-complex graphics in designing icons. Minimize composite icons so that the icon does not become confusing due to the large number of primitives or structural components. Ideally the primitives should come from the existing domain of the user's experience.

Gittens (1986); Nawrowki, 1972.

a. A literal, simplistic representation of the underlying objects structure should be used rather than an arbitrarily different representation.

Gittens (1986).

b. The best design of icons tend to be minature canonical representations of the physical objects to which they refer, which shows or even exaggerates the objects distinctive features.

See 3.2.3.2. Concrete concepts.
Rubenstein and Hersch, 1984; Hemenway, 1981.

c. Applicable to both two and three dimensional symbolic representations, consider using Leeuwenberg's mathematical coding language or other coding systems to measure the structural complexity of icons.

See 3.2.3.1.1. Gestalt principles: Pragnanz.
Leeuwenberg (1968, 1971); Van Tuijl (1980).

3.2.3.4. Consistency.

a. The meanings assigned to icons should remain consistent across displays that are to be presented together. Icons should be standardized within a system and, where possible among systems with the same users.

b. As possible to do so, use a common set of primitives and boundary shapes for all icons in the interface. The consistent use of graphic primitives and boundary shapes will help formulate semantic determinants, the meaning of an icon and the relationships of meanings of a set of icons. In this respect, the user will be able to interpret more easily the icons and make valid inferences about the characteristics of their underlying objects, even for new icons.

See 3.2.3.1.2. Meaningfulness of form.
Gittens (1986); Ives (1982); Sumikawa (1985).

3.2.3.5. Opposing functions. Represent opposing functions with icons which mirror each other.

Gittens (1986)

3.2.3.6. Figure grounds. The ground form of a icon should be clear and stable.

See 3.2.3.1.4. Rules of figure ground organization.
Gittens (1986).

3.2.3.6.1. Boundary. The boundary lines around an icon should be solid, closed, and contrast-bounded, with the corners as smooth as possible.

3.2.3.6.1.1. Unclosed boundary. If the boundary lines around an icon terminate without converging, users may perceive a closure where none exists.

3.2.3.6.1.2. Contrast. The constrast between the figure ground and the underlying display can be used effectively to enhance the icon and background boundary. As possible to do so, avoid using color alone to provide a contrast, rather use a redundant coding strategy that utilizes color and some other visual dimension. Do not use blue as a distinguishing component.

See 3.2.3.1. Gestalt principles; 3.2.5. Aiding techniques; 2.4.6. Color coding.
Gittens (1986).

3.2.3.7. Size and location.

a. Display targets, whether alphanumeric or iconic, should be as large as possible in order to reduce positioning time and error rate. Fitts's Law predicts that the hand movement time to position a target from one location to another increases with the distance moved and decreases with the size of the target.

b. As possible to do so, the ability to change the size and location of icons should be consistent with the facilities provided for other components of the dialogue, especially windows.

c. When an icon is used to code data categories as many as five different sizes can be used. However, size coding of icons should be restricted to less dense displays; with two or three different sizes as a practical limit.

d. If multiple sizes are employed for the same symbol, the next larger symbol should be at least 1.5 times as big as the next smaller symbol.

See 2.4.5. Symbol coding; 3.1.2. Positioning; 4.3. Windows and screens.
Engel and Granda (1975); Foley, Wallace and Chan (1984); Gittens (1986); Ives (1982); MIL-STD-1472 5.15.3.3.6.; Smith and Mosier (1986).

3.2.3.8. Color. Use color with discretion and for specific purposes. Color can be used effectively to denote the association and attributes of icon objects and to provide contrast when a redundant coding strategy is used.

See 2.4.6. Color coding; 3.2.3.6.1.2. Contrast; 3.2.5. Aiding techniques.
Gittens (1986).

3.2.3.9. Iconic labels. Alphanumeric labels should be placed beneath the symbol or definitions of icons should be available to the user (e.g., through selective call-up facilities where the user can obtain the meanings or other detailed information about symbolic representations).

See 2.4.5. Symbol coding.

3.2.3.10. Iconic coding schemes. To avoid an overly complex display, a coding scheme using icons should consist of no more than twenty unique shapes.

Ives (1982).

3.2.4. Iconic forms. Use the guidelines below to answer questions about how to use various iconic forms in the graphic interface.

3.2.4.1. Technological icons. When the system will be used by different cultural groups, use technological icons (as possible to do so) rather than natural objects so that the icons will be interpreted consistently by the varying cultural groups.

a. For example, denote area definitions by triangles or circles, maximum sizes by squares and diamond shapes, and perimeters by lines with apex characters such as "+" and "*". In using squares and oblongs the recommended aspect ratios are 1:1, 1:2 and 1:3, etc.

Gittens (1986).

3.2.4.2. Metaphors. A metaphor relies on attributes of a physical, external environment with which the user is familiar, being directly transferable to the objects in the computer system. Metaphors should be tested with users to confirm their intended meanings.

a. Do not use metaphors if self-contained icons of equal useability can be designed. Metaphors can be dysfunctional if users make inferences beyond their intended meanings whereby the functionality of the system could be affected adversely.

b. As possible to do so, use technological icons in the metaphor in preference to natural or cultural objects. Technological icons can facilitate the users transition to the use of other interactive media and can make the system more useable by diverse cultural groups.

c. Metaphors should be consistent for the objects provided (e.g., file deletion with recovery = waste paper bin, permanent deletion = shredder).

d. The emotional tone of a metaphor should not be distasteful or inappropriate. For example, a sewage disposal system is an inappropriate metaphor for an electronic message system.

See 3.2.4.1. Technological icons; 3.2.3.2. Concrete Concepts; 3.2.2.2. Transition to other media.
Gittens (1986); Shneiderman (1987).

3.2.4.3. Metaphors as design model. Avoid overuse of the "office metaphor" as the design model. Use a systematic design process where user characteristics (e.g. skill, knowledge, abilities and culture), tasks to be performed and software and hardware characteristics are considered to select the design model.

a. As possible to do so, provide a variety of metaphors. Users can benefit from the use of more than one model of the system as their experience increases and several metaphors can also help personalize the system, which is especially important when users vary widely in individual characteristics.

b. Provide for a clear explanation of the limits of the metaphor and monitor usage.

c. As possible to do so, provide facilities to migrate to other metaphors or media.

See3.2.2. Disadvantages.
Gittens (1986).

3.2.5. Aiding techniques.

3.2.5.1. Three-dimensional symbols. For three-dimensional symbols provide a multiview capability, that is, different vertical or horizontal viewing angles, as well as different coverage. The capability will provide the user with a choice of views that best satisfy information needs.

See 2.5.7. Three or more dimensional forms.
Louis (1984).

3.2.5.2. Transition. Provide facilities within the interface for users to migrate to other collections of icons, other metaphors and other media (text and commands).

Gittens (1986).

Section 4. Screen Layout and Display Characteristics

This section provides selected guidelines on screen layout and display characteristics that are important from the graphics design perspective. Some generic guidelines that address major design considerations are also included. More extensive coverage of screen format and display characteristics can be found in Freeman (1986), Galitz (1981), and Rupp (1984).

4.1. User control. To optimize the use of screen space and to accommodate individual differences in expertise among users, give the user some control over screen layout.

a. For example, as possible to do so, allow users to control the positions and dimensions of windows. For example, novices typically will enlarge prompt windows to show as much helpful material as possible. Experts will shrink this window to maximize the amount of other information displayed.

See 4.3. Windows and screens.
Newman and Sproull (1979).

4.2. Menus.

4.2.1. Organization: single-level vs. hierarchical. If the set of alternatives is small enough to be contained in the available screen space, a single-level menu can be used. Otherwise, use a hierarchical menu or sequential displays of single-level menus.

4.2.1.1. Positioning techniques. To assist the user in maintaining orientation when using a multi-framed menu structure (hierarchical or sequential displays of single-level menus), consider including techniques to indicate position in the menu.

a. For sequential displays of single-level menus, consider using a simple visual presentation to indicate position in the sequence, such as a "position marker". For example, position in the first frame of a menu with 6 frames can be indicated by a position marker that shows +-----, position in the second frame can be indicated by -+----, and so on.

b. Consider making available to the user a graphic of a hierarchical menu, such as a tree structure or flow chart that presents the menu structure in an abbreviated format. The current position should be highlighted. In systems where display space is not a constraint and all items of a hierarchical menu can be adequately labeled and displayed, consider permitting the user to make menu selections using the graphic. However, any visual representation selected for hierarchical menus should be tested for effectiveness.

Schneiderman (1987).

4.2.1.2. Navigational aids. Consider providing navigational aids to assist users in moving through menu selections. These aids might include control commands to traverse a hierarchy, such as move to the top of the hierarchy and move up one level of the hierarchy; a capability to go directly to a few frequently used nodes of a tree; and commands to flip pages forward and backward in sequentially displayed single-level menus.

Foley, Wallace and Chan (1984).

4.2.1.3. Order of Items. Avoid a random organization. Generally an alphabetical, frequency of use and a logical (functional) ordering can be used together or separately to construct menus. Commands in a hierachical menu usually are arranged based on a logical or functional grouping.

See Graphic Aids.
Foley, Wallace and Chan (1984).

4.2.2. Graphic menus. Organization of icons in graphical menus may conform to same principles of organization used with textual menus.

See 4.2.1. Organization-Single-level vs. hierarchical; 3.2. Iconic Dialogue.
Foley, Wallace and Chan (1984).

4.3. Windows and screens.

4.3.1. Multiple windows and screens. Multiple windows and multiple screens should support the user's expectations about the pattern of the display.

See 2.5.6.2. Graphic aids.
Norman, Weldon and Shneiderman (1986).

4.3.2. Graphic manipulation. Consider providing facilities for the exposure and hiding of overlapping windows and for the stretching and contraction of windows. These types of graphic manipulation capabilities will allow the user to tailor the display to one's individual needs and preferences and may also help to optimize the use of screen space.

4.4. Cursors. Use different cursors to signal system processes and states to the user.

4.4.1. Cursor forms. Choose cursor forms that are distinctively different from the alphanumerics, special characters or graphic elements used on the displays. Intensity, color, blink and other coding techniques also may be used to differentiate the cursor from the rest of the displayed information.

4.4.2. Cursor positioning and movement. Especially critical for graphic data entry tasks, the user needs an efficient means to position or move the cursor around on the display and to signal to the computer when the desired location has been reached.

4.4.2.1. Ease and accuracy. Incorporate techniques in the interface that will provide users with an easy and accurate means for positioning a displayed cursor to select locations, to select different display elements, and to perform other tasks associated with the entry, manipulation or editing of graphic's data or other display elements.

4.4.2.2. Confirmation. Provide techniques that will permit the user to confirm the position of the display cursor. The position selected for the cursor should be confirmed as a separate action. that is the user should first position the cursor at the desired location and then confirm that position to the computer. Confirmation is not recommended for pathing tasks.

4.4.2.3. No rotation. To achieve efficient user performance, there should be no rotation in the positioning-device-to-screen transformation, to include those situations where the viewing transformation from world to screen coordinates does include rotation. Specifically, the cursor (or other graphic object being positioned) should move in the same direction as the user's hand while the control device is being manipulated. For example, the movement of the hand to the right should cause the screen cursor to move to the right.

See 3.1.2. Positioning.
Foley, Wallace, Chan (1984); Marcus (1984); Smith and Mosier (1986).

4.5. Area for item selection. The display area for selecting an item should be as large as possible (i.e., when selecting an item for repositioning, editing, etc.). The minimum area for selection should be the length of the item plus half the height of the item. Ideally, the user should be able to specify a symbol, a line segment or text string anywhere within the area of the item or within its surrounding area.

Engel and Granda (1975).

4.6. Display device characteristics.

Consider the tasks to be executed using the computer system and the type of environment in which the system will be operated to identify the performance requirements for display device characteristics (e.g., values of spatial resolution and intensity resolution). Command and control systems will be operated in numerous types of environments under suboptimal viewing conditions by users whose cognitive, perceptual and motor functioning may be degraded by the stress of war. Also, if a command and control system is to be responsive to the informational demands of the fast paced, battlefield environment, the system will require a highly dynamic, highly interactive user-interface with rapid screen update of complex images. For these reasons, optimal performance levels of display device characteristics are generally required for command and control systems.

4.6.1. Evaluation. To evaluate a display device or to compare the quality and performance capabilities of different display devices, consider the extent to which the display's spatial resolution, intensity resolution, color capability, linearity, writing speed, brightness and selective erasibility capability satisfy task and environment requirements.

4.6.1.1. Spatial resolution. To select a particular spot in an image, one specifies a pair of coordinates (x and y) in the computer. The number of bits available for specifying a coordinate determines the resolution in that coordinate. Typical resolution values for computer graphics displays range from a low of 1:256 to a high of 1:4096.

4.6.1.2. Intensity resolution. Intensity resolution is brightness of light emanating from a selected point (pixel) of the display. Intensity resolution normally ranges from a minimum of two for a bi-level (black and white) display, to a maximum of 256. High values of intensity resolution are required for gray-tone images. Line drawings seldom require more than eight intensity levels.

Freeman (1986).

4.6.1.3. Color capability. In a full-color graphics display, the user can generate a large set of colors, defined in terms of hue, saturation, and intensity, by appropriately mixing red,

green, and blue light sources of different intensity. The number of displayable colors depends on the ranges in intensity available for each of the three primary colors, which can range from as few as eight in low-cost displays into the millions in high-performance displays.

4.6.1.4. Linearity of the display. The linearity of a display is measured by the accuracy to which geometric properties of the representation are preserved. In a display with high linearity, specifying a given horizontal line segment to be twice as long as another segment yields a segment that is indeed twice as long, within a tolerance that does not exceed the resolution of the display. Also in high linearity displays, straight lines tend to be as straight and as much to the desired slope as the discreteness of the display permits.

Freeman, (1986).

4.6.1.5. Writing speed. Writing speed refers to the rate with which graphics can be drawn on the display. A user request for a new image or a change in an existing image should be carried out almost instantly. The delay in carrying out a user request should be no more than 1 to 2 seconds. Longer delays may disrupt the continuity of the user's thought processes.

4.6.1.6. Brightness. Display brightness determines the level of ambient light under which the display can be comfortably viewed. Brightness is the psychological perception of light intensity and is related closely to luminance (that is, the luminous intensity per unit area, which is a photometric quantity). Both brightness and contrast, the ratio of the difference between the maximum and minimum luminance to their sum, affect display visibility.

4.6.1.7. Selective erasability. The display device should have the capability for selective erasability. The user should be able to erase any portion of a graphics image without altering the rest of the image. It should not be necessary for the user to first erase the entire image, which is subsequently redrawn without the undesired portion.

4.6.1.8. Other display characteristics. Other characteristics of the display device to consider in evaluating the appropriateness of the display device are inherent storage, power requirements, life expectancy, resistance to shock and vibration, and cost.

Freeman (1986).

5. References

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